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QUANTITY-DISTANCE FRAGMENT HAZARD COMPUTER PROGRAM (FRAGHAZ)

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The Fragment Hazard Computer Program (FRAGHAZ) written in FORTRAN 77 is described by general and detailed descriptions. FRAGHAZ is designed as a tool to estimate the fragment hazards produced by the inadvertent detonation of munitions stacks. Fragmentation data are derived from small-scale arena tests. A separate trajectory is calculated for each recovered fragment using Fourth-Order Range-Kutta numerical integration procedures. Any target may be simulated which can be approximated by a rectangular parallepiped. Wind and fragment ricochet effects are included. Output is expressed as fragment hazard range versus number of munition units for both areal number density and probability of hit criteria.

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FOREWORD

The Quantity-Distance Fragment Hazard (FRAGHAZ) Computer Program was developed for the Department of Defense Explosives Safety Board (DDESB) by Frank McCleskey while employed at the Naval Surface Warfare Center (NSWC) from 1981 to 1986. The documentation of the program was accomplished by the author while an employee of Kilkeary, Scott & Associates, Inc., in 1987 under Navy Contract.

The FRAGHAZ program had its beginnings in the early 1970s. The initial concepts were developed by Richard T. Ramsey of NSWC, under the able direction of Dr. Thomas A. Zaker of the DDESB. This program is dedicated to the memory of both these gentlemen who contributed so much to the field of explosives safety analysis.

Following Dr. Zaker's death in 1986, Dr. Jerry M. Ward has directed the program at the DDESB.

The individuals who made significant contributions in the development of the FRAGHAZ computer program are W. D. Smith, J. G. Powell, R. J. Sawyer, and R. E. Baker, of NSWC and M. Reches, AMSAA; M. Miller, O. Smith, and D. Webber, CRDC, Aberdeen, Maryland.

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INTRODUCTION

Historically, hazards from stacks of explosive ordnance have been stated in terms of hazard distance due to blast overpressures. These hazard distances, presented as quantity versus distance (QD criteria), have not adequately addressed the fragment hazards. The fragment hazards were specified in terms of specific number of weapons and were derived using many simplifying assumptions. As a result, the validity of these QD criteria have always been questionable.

The Department of Defense Explosives Safety Board (DDESB) decided to begin detailed studies and experiments concerning the hazards posed by fragments from stacks of detonating munitions in the early 1970s. The Naval Surface Warfare Center (NSWC) was requested to characterize weapons of interest to the DDESB and to establish analytical techniques that would predict the fragment hazards for stored munitions.

Many fragmentation experiments were conducted and a number of predictive analytical techniques were explored. The analytical techniques were all characterized by integral and differential equations whose solutions would provide estimates of hazard distances for fragmenting munitions. These analytical approaches suffered from the need to restrict the number of variables to a manageable level. As a result, many variables had to be averaged or held constant. Many conditions such as wind, ricochet, and variable drag coefficient had to be ignored to make the equations manageable.

In 1981, recognizing the limitations of the analytical methods, a new approach was established that had the promise of overcoming the restrictions imposed by analytical equations. The new approach relied on numerical procedures where as many equations as needed could be solved sequentially. In the numerical procedure, a complete trajectory for each fragment representing a particular munition is calculated, and hazard calculations made when the trajectory intersected the target. These numerical procedures are often referred to as MONTE CARLO or FULL FACTORIAL procedures. This report contains the description of numerical procedures currently established for predicting the hazards from fragmenting munitions. There is a general description designed to orient the reader as to the many qualitative aspects of the procedure. This is followed by a detailed line-by-line description of the computer code. Supporting this thorough description of the computer code is a number of appendices containing information too detailed to be included in the main body of the report. Such things as glossaries, mathematical proofs, program listings, and example problems are included in the appendices.

Although future changes are inevitable, the computer program has advanced to a stage where documentation is warranted. All significant factors affecting the hazards from fragments have been incorporated. The program is coded in Microsoft FORTRAN 77, which is common to many computers ranging from MICROS to MAIN FRAMES. FORTRAN 77 represents a compromise between BASIC and FORTRAN IV. The program has been structured to minimize running time such that it can be run practically on MICRO computers. A typical run on the IBM PC-AT using compiled FORTRAN 77 takes approximately 6 hr, whereas on a MAIN FRAME the run would be measured in minutes.

GENERAL PROGRAM DESCRIPTION

The QD Fragment Hazard (FRAGHAZ) Computer Program provides a method for predicting the fragment hazard produced by the detonation of munitions. FRAGHAZ requires fragment characteristic data obtained from small-scale tests representative of larger stacks of munitions. In the case of 155mm projectiles, for example, the small-scale test may consist of one or more pallets (eight projectiles per pallet) positioned and detonated to yield a representative sample of fragment data from an entire stack. Full trajectories are calculated for each fragment recovered in the small-scale test. Appropriate calculations are made during the fragment trajectory to establish the hazard to a specified target.

STACK FRAGMENTATION CHARACTERISTICS

Past tests have demonstrated that virtually all the fragments going downrange are produced by the munitions (projectiles, bombs, etc.) on the face of the stack toward the target area. Fragmentation from the ordnance in the interior of the stack is, for the most part, contained within the stack. When a stack with units close together is detonated, fragment jets are produced between adjacent munitions on the face of the stack. The width of the jet depends on the method of stack initiation. When all units are detonated simultaneously, the jet is typically 10 deg wide. If only one or two donor units are initially detonated, the jet width is more typically 20 to 30 deg. Stack detonation by donor units is called natural communication and all current testing (presented here) uses this technique.

The jet produced between adjacent units is called an interaction area. The greatest fragment densities and highest fragment velocities are produced within the interaction areas. For safety purposes, the fragmentation characteristics of the interaction areas are used for input to the computer model. The interaction areas overlap at relatively short distances downrange and their effects can therefore be added to represent the cumulative effects of large ammunition stacks.

HAZARD CRITERIA

The FRAGHAZ program requires that hazard criteria be specified for the target being considered. Most work to date has been concerned with the personnel target. The DDESB has specified the following hazard criteria for personnel:

1. Fragment impact kinetic energy of at least 58 ft-lb
2. Hazardous fragment areal number density of at least one hazardous fragment per 600 ft^2

The hazardous fragment areal number density criterion is approximately equivalent to a hit probability of 0.01 given that the presented area of a man is considered to be 6.2 ft^2. Similar criteria must be specified for other targets being considered.

MONTE CARLO AND FULL FACTORIAL OPTIONS

FRAGHAZ runs under a MONTE CARLO or FULL FACTORIAL option. Both options provide methods for handling the uncertainty associated with random variables. The program includes seven random variables for each option:

1. Initial fragment elevation angle
2. Initial fragment velocity
3. Fragment drag coefficient
4. Height of the fragment trajectory origin above the ground surface
5. Soil constant for ricochet
6. Wind speed
7. Altitude of the ammunition stack site

The first three random variables have to do with the specific characteristics of each fragment. The remaining four variables are more like background conditions.

The following analogous terms are associated with the two options:

MONTE CARLO	FULL FACTORIAL
Variable	Factor
Value	Level
Replication	Treatment

In the MONTE CARLO procedure a variable is any one of the random variables listed above. In the FULL FACTORIAL option, these random variables are called factors. Likewise, value and level pertain to any single value for any single random variable. Replication and treatment are also essentially synonymous, and are explained in the following.

In the MONTE CARLO option, each replication represents a simulation of a full-scale test. For example, suppose there were 250 fragments recovered in a small-scale test representing a particular munition. Each random variable associated with the fragments would have a known or assumed range of uncertainty. Random numbers are then used to designate a particular value for each random variable. Trajectories would be calculated for each of the 250 fragments with an effective number of fragments associated with each trajectory commensurate with the full-scale stack. Hazardous intersections with the target would be recorded and accumulated in the program. This would constitute one replication. Because of the uncertainty in the random variables, this would constitute only one possible outcome for the full-scale ammunition stack under consideration. As a result a second replication would be conducted using a new set of random numbers to define new values for the random variables. A new outcome would be produced and would be recorded and accumulated along with the outcome of the first replication. This procedure would continue until the outcomes of as many as 60 replications were recorded and accumulated. At that time the program calculates the desired hazard statistics from the hazard data in each replication. These final statistics can be in the form of averages, minima, maxima, percentiles, etc. If there were 250 fragments and 60 replications, then the program would have to calculate 250 x 60 = 15000 complete trajectories. Trajectory calculations consume about 90 percent of the program running time. The remaining 10 percent is taken up with bookkeeping (recording and accumulating hazard data) and output calculations.

The FULL FACTORIAL option differs from the MONTE CARLO option only in the way the values of the random variables are selected. In the MONTE CARLO option, if we had 60 replications, then 60 different values for each random variable for a particular fragment would be selected. For example, suppose a single

fragment had an elevation angle somewhere between 20 and 30 deg as determined in the small-scale test. We would only know that the fragment elevation was between these two limits and not its exact value. For each replication we would use a random number to specify the exact value of the elevation angle for that particular fragment; that is, 60 different angles between 20 and 30 deg. In the FULL FACTORIAL option, only a few levels would be specified. For example, taking three random variables (factors) -- elevation angle, height of origin, and drag coefficient, the levels might be specified as follows:

FACTOR	LEVELS
E	0.1, 0.5, 0.9
H	0.5
C_D	0.1, 0.9

The levels represent the percent up from the minimum. In the previous example, the elevation angle for the fragment was known to be between 20 and 30 deg. The levels being 0.1, 0.5, 0.9 the corresponding angles to be considered in the FULL FACTORIAL option would be 21, 25 and 29 deg. These would be the only angles considered. The treatments would be all the combinations of the three factor levels as presented below:

TREATMENT	FACTOR LEVELS
1	E (0.1), H (0.5), C_D (0.1)
2	E (0.1), H (0.5), C_D (0.9)
3	E (0.5), H (0.5), C_D (0.1)
4	E (0.5), H (0.5), C_D (0.9)
5	E (0.9), H (0.5), C_D (0.1)
6	E (0.9), H (0.5), C_D (0.9)

The number of treatments is equal to the product of the number of factor levels, 3 x 1 x 2 = 6. Since H has only one level, it is constant throughout the procedure. This might be the case if we knew from previous experience that the outcome was insensitive to this variable. Again, trajectories would be calculated for all 250 fragments for each treatment using the factor level combinations given above. The recording, accumulating, and output would be calculated in the same way as for the MONTE CARLO option.

Each of the calculation options has its strengths and weaknesses. The nature of the problem being considered will usually dictate the choice. The program as written in this report uses a personnel target. However, with modification, the FRAGHAZ program has been used to evaluate barricades and compute probability of hit for vehicles moving on a public traffic route.

HAZARD VOLUME

Figure 1 shows the essential elements of the model. Since interaction areas overlap at relatively short distances downrange, all fragments are assumed to emanate from a vertical line at the center of the stack. The height of the vertical line is made consistent with the typical stack height of the ordnance under consideration. The height at which an individual fragment originates is selected randomly for the MONTE CARLO option and at specific levels for the FULL FACTORIAL option. A pie-shaped sector is used to

simulate the downrange hazard volume. A hazardous fragment is only of concern when its trajectory lies within the pie-shaped hazard volume. The height of the sector is equal to the height of the target selected. In Figure 1, this height is shown for a personnel target. The angular width of the sector is typically 10 deg. This value has been selected to match the 10-deg sector width used in the fragment pickup from full-scale tests. In this way, one can compare the program predictions with actual pickup test data to gage the validity of the computer model. The hazard volume is divided into 100-ft segments from zero to the maximum range specified for the program calculations. Without wind, the maximum calculated range is on the order of 4800 ft. All calculations of fragment numbers, fragment density, and probabilities of hit are made with reference to these 100-ft segments. Later in the simulation, the results in each 100-ft segment may be combined to yield results for 200, 300, and 400-ft increments. These larger increments sometimes assist in plotting and interpreting the output data.

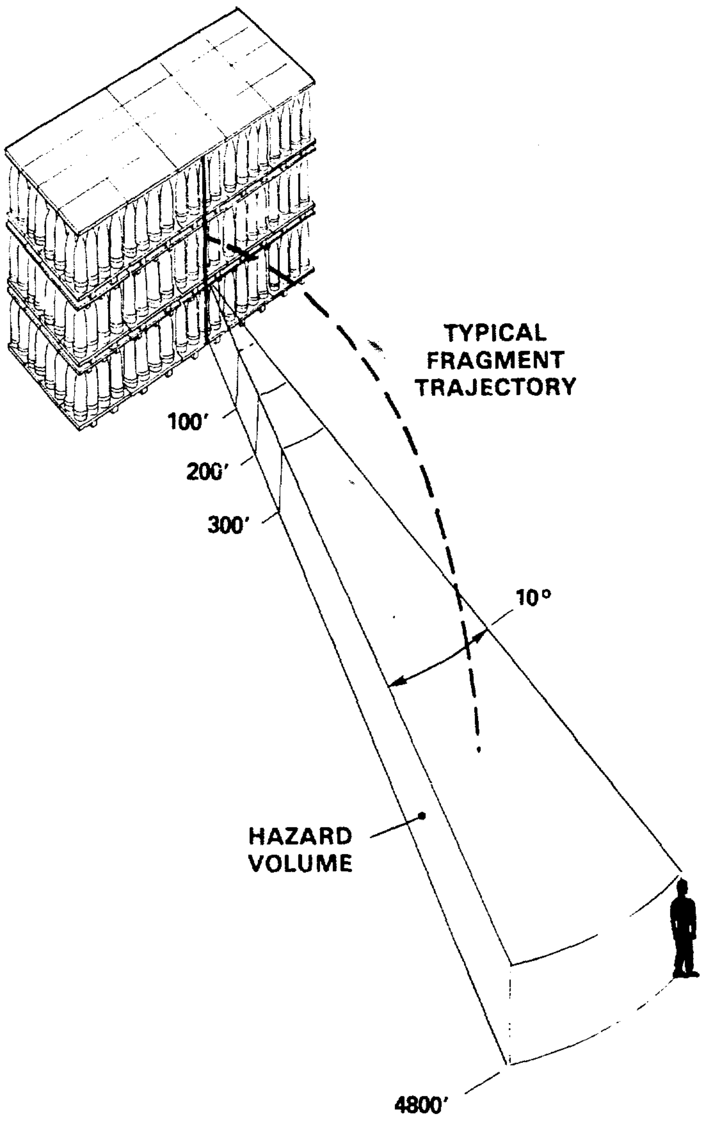


FIGURE 1. STACK FRAGMENTATION SIMULATION

FRAGMENT TRAJECTORY

Figure 2 shows a more detailed picture of the fragment trajectory. Wind is included as a two-dimensional velocity vector, which can have both range and cross-range components. There is no vertical component to the wind vector, since this is seldom reported in practice. The wind, therefore, is always contained in a horizontal plane at the point of calculation. The origin of the trajectory is at a designated height selected by the MONTE CARLO or FULL FACTORIAL option. The trajectory is calculated using a fourth-order Runge-Kutta routine. Calculations can be made in three dimensions with the effects of wind included. The Runge-Kutta routine requires only initial conditions for fragment velocity and elevation angle at the origin. These conditions are obtained from small-scale arena tests of the munition being considered. Each point along the trajectory is calculated from the conditions existing at the previous point. The velocity and trajectory angle are computed at each point. When the trajectory is within the hazard volume, the kinetic energy of the fragment is calculated and compared with the hazard kinetic energy criterion to determine whether the fragment is hazardous or not. The trajectory angle is used in subsequent fragment density and probability of hit calculations. Range, cross-range, and distance are computed and are used for associating the hazard to a particular 100-ft-hazard segment. Currently, the initial fragment velocity vector is constrained to the vertical X-Y plane. However, since the model uses a true three-dimensional routine, there is complete three-dimensional freedom for establishing the initial conditions. Trajectory calculations are made for each fragment recovered in the small-scale arena test.

A tail wind has three adverse effects on hazard conditions. First, a tail wind will increase the range of a fragment. Second, it will increase the striking velocity of a fragment thereby increasing its hazard to the target. Third, a tail wind will decrease the angle of strike thereby increasing the presented area of a target with a large vertical dimension (a man for example). The increased presented area results in larger probabilities of hit. The increased range due to a tail wind is approximately equal to the time of flight multiplied by the wind speed. In the far range where the time of flight can be approximately 10 sec, a tail wind speed of 50 ft/s will result in a range increase of about 500 ft.

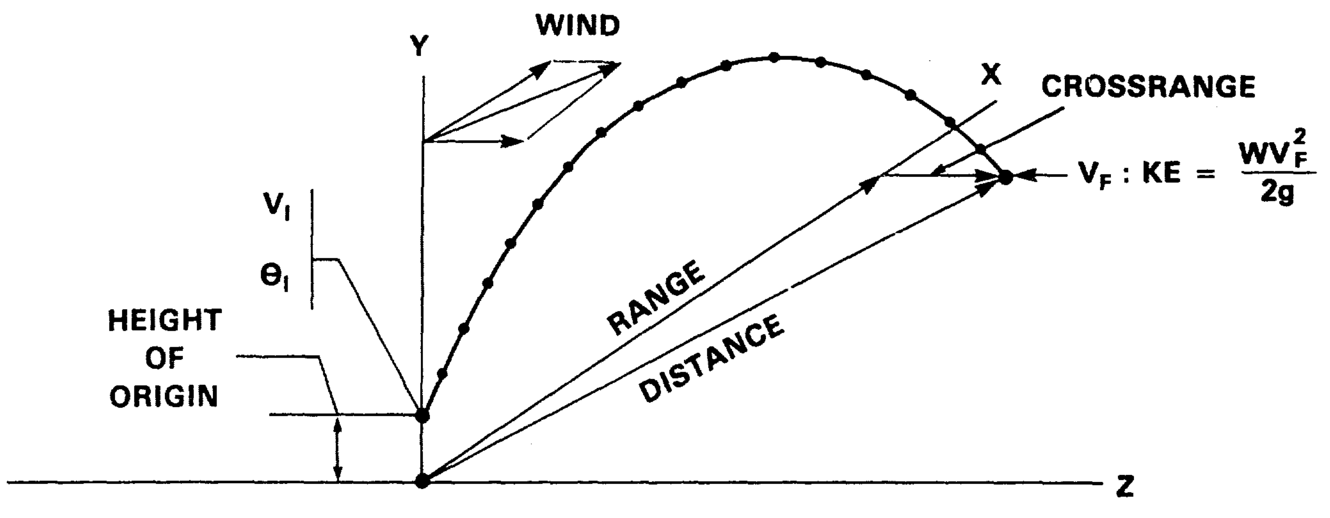


FIGURE 2. FRAGMENT TRAJECTORY

Figure 3 shows the two types of trajectories considered in the FRAGHAZ model. The normal or non-ricochet trajectory has been considered previously. The ricochet trajectory is based on experiments conducted by the Ballistic Research Laboratories at Aberdeen, Maryland, in the late 1960s.[1] In both types of trajectories the points at which the fragment strikes the ground and either enters or leaves the hazard volume (large dots in Figure 3) are accurately calculated in the model. This permits the hazard data to be definitely associated with the proper 100-ft hazard segment. When a fragment impacts the ground, its impact angle is compared with a critical ricochet angle to determine whether the fragment will ricochet. The critical ricochet angle is dependent on the type of soil. Once it is determined that the fragment will ricochet, the angle and velocity of ricochet are determined from the incident angle and velocity together with the effect of soil type.

Since all the dynamic characteristics of the fragment are known at each point calculated in the Runge-Kutta routine, all fragment hazard data can be calculated at each point. When more than one point is contained in a 100-ft hazard increment, averages are used to determine the hazard data for the increment.

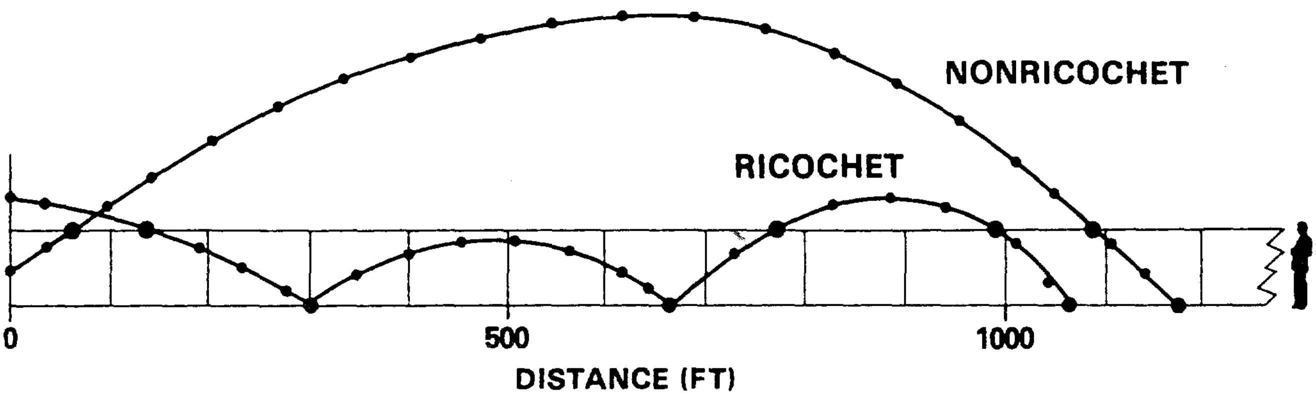


FIGURE 3. TYPES OF TRAJECTORIES

HAZARD CALCULATIONS

Figure 4 shows how hazard density and hazard probability of hit are calculated for a personnel target. The number of hazardous fragments (N_F) is dependent on the number of ordnance units on the face of the stack toward the target area. Since the trajectories are calculated point by point, the 100-ft hazard volume increment through which the trajectory is passing can be determined. The fragment mass and velocity are also known at each point and, therefore, it can be determined whether the fragment possesses sufficient kinetic energy to exceed the hazardous kinetic energy criterion. After the fragment has been determined hazardous, the presented areas of the target (represented as a parallelepiped) and of the total volume of the 100-ft hazard volume segment can be calculated in the plane perpendicular to the fragment trajectory. This can be done because the trajectory angle with respect to the horizontal is calculated at each point along the trajectory. Once the presented areas are known, the density and probability of hit can be calculated using the formulas shown in Figure 4.

[1]Reches, M., *Fragment Ricochet Off Homogeneous Soils and Its Effects on Weapon Lethality (U)*, Army Material Systems Analysis Agency Technical Memorandum No. 79, August 1970 (CONFIDENTIAL).

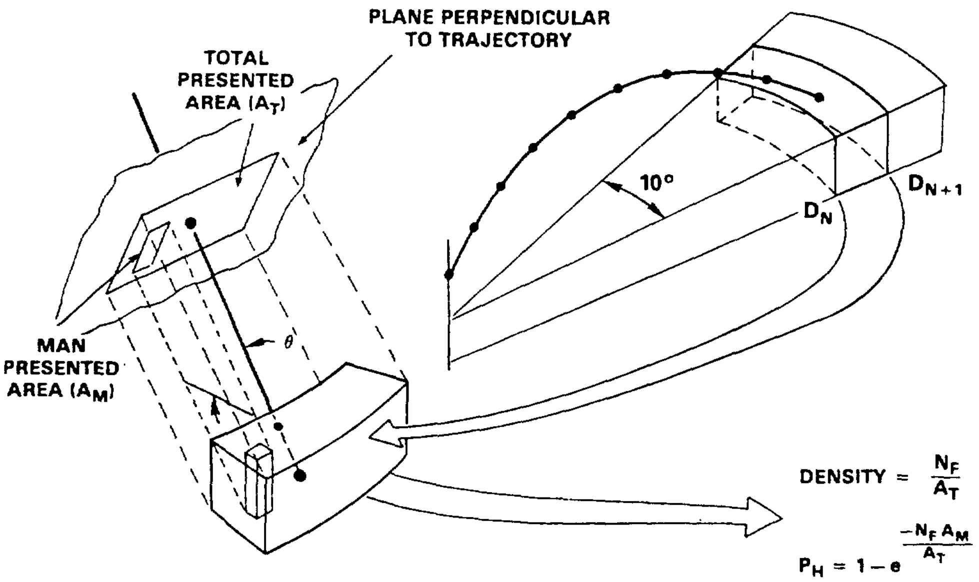


FIGURE 4. HAZARD CALCULATIONS

TYPICAL FRAGMENT DATA INPUT

Table 1 shows typical fragmentation input data. Each fragment recovered in the small-scale arena test has its own set of five elements.

TABLE 1. TYPICAL FRAGMENTATION INPUT DATA

Fragment No.	Polar Angle (deg)	Weight (grains)	Initial Velocity (ft/s)	A/M (in.^{2}/lb)	Presented Area Ratio (max/avg)
1	10	623	3246	10.24	1.73
2	10	815	3246	9.16	1.26
3	20	1522	4112	11.31	1.41
4	30	711	4112	6.43	1.64
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
89	60	1152	5316	7.37	1.59
90	60	847	5316	8.68	1.42
91	70	1634	6123	11.74	1.65
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
247	100	1713	5312	8.62	1.59
248	100	652	5312	9.14	1.27
249	110	918	6597	6.23	1.64
250	110	1314	6597	11.89	1.59

Usually all fragments less than 300 grains are eliminated, since they seldom reach and are usually nonhazardous in the far-field. The upper bound of the polar zone is listed under Polar Angle. In this case, the polar zones are 10-deg wide. A polar angle of 70 deg identifies the 60 to 70-deg polar zone. The lower limit of the 10-deg elevation zone used in the program is equal to

$$EA = 90 - PA$$

where

EA = Lower angle of elevation zone
PA = Upper angle of polar zone

A 60 to 70-deg polar zone would therefore be associated with the 20 to 30 deg elevation zone as measured from the horizontal. A 100 to 110-deg polar zone would be associated with the -20 to -10-deg elevation zone. Currently the maximum critical ricochet angle is about 20 deg and, therefore, collection of fragments in polar zones greater than 110 deg is not necessary. In anticipation of possible future changes, tests have been designed to collect fragments to the 130-deg polar angle.

The fragment weight is measured by a scale and used in kinetic energy and A/M ratio calculations. The velocity is the average initial velocity for a particular 10-deg polar zone. As such, all fragments from the same polar zone have the same average initial velocity.

The A/M ratio is used in the drag equation. It is the ratio of the average presented area (in.^{2}) to the weight (lb) of a fragment.

The Presented Area Ratio is the maximum presented area divided by the average presented area of the fragment. This ratio correlates with the low subsonic ($M = 0.1$) drag coefficient. By using this ratio, the uncertainty in the drag coefficient for a fragment can be reduced by about 40 percent as explained under **FUTURE IMPROVEMENTS** (Drag Coefficients) in the **DETAILED PROGRAM DESCRIPTION SECTION.**

OUTPUT

There are three basic outputs for the program: Number of Final Ground Impacts versus Distance, Hazard Density and Probability of Hit versus Distance, and Number of Units Required to exceed the density and P-Hit Hazard Criteria versus Distance.

Number of Final Ground Impacts Versus Distance

Suppose we have 250 fragments representing the munition and we use 60 replications or treatments. For the first replication or treatment, the 250 fragments will come to rest in a set of 100-ft hazard segments. On the subsequent replication, the 250 fragments will come to rest with a different distribution because of the different values used for the input variables. We will end up with 60 different distributions of final ground impacts from ricochet and nonricochet fragments. The 60 values for each 100-ft hazard segment are then sorted from the smallest to the largest numbers. The first value in the sorted numbers becomes the minimum number of final ground impacts for the particular 100-ft hazard segment being considered. Likewise the 60th value is the maximum number. Adding all 60 values and dividing the sum by 60 yields the average number of final ground impacts for the associated 100-ft hazard increment. The minimum and maximum number are compared with actual ground pickup from full-scale tests. If the predictive capability of the program is valid, then the actual number of fragments picked up in a full-scale test (analogous to one replication or treatment) should fall within the maximum and minimum limits predicted by the program. Currently two such comparisons are available. Figures 5 and 6 show this comparison for 155mm projectiles and Mk 82 GP Bombs, respectively. The comparisons support the contention that the predictive capabilities of the program are valid.

Hazard Density and Probability of Hit

These quantities are handled similar to the number of Final Impacts. Assuming 60 replications or treatments, there will be density and probability of hit entries in each 100-ft hazard segment for each replication or treatment. By sorting from smallest to largest, we may establish minimum, maximum, and average values. In calculating these quantities, only those fragments exceeding the kinetic energy criterion are used.

An additional hazard measure is used in calculating hazard density and probability of hit. This measure is called a percentile value. The percentile measurement may be thought of as a confidence level. If we were to use a 90th percentile value, one could understand this to mean that we would be 90 percent confident that the hazard densities and probabilities of hit would not exceed the values listed. The 90th percentile value will have 10 percent of the distribution above it. For example, after sorting the 60 values at a particular 100-ft hazard segment, the 54th largest would be the 90th percentile value.

Number of Units to Exceed the Hazard Criterion

These data are used primarily for establishing the hazard ranges versus number of units for stacked munitions of interest to the DDESB. Two tables are output, one based on the hazard density criterion and one based on the hazard probability of hit criterion. Table 2 is an example of the output table based on the hazard density criterion. The number of units required is equal to the hazard density criterion (one hazardous fragment per 600 ft^2) divided by the hazard density for one unit. Note the reciprocal nature of the calculation; the higher the hazard density the less the number of units required and the greater the hazard. Only the 90th percentile column is shown; the other columns would have analogous entries.

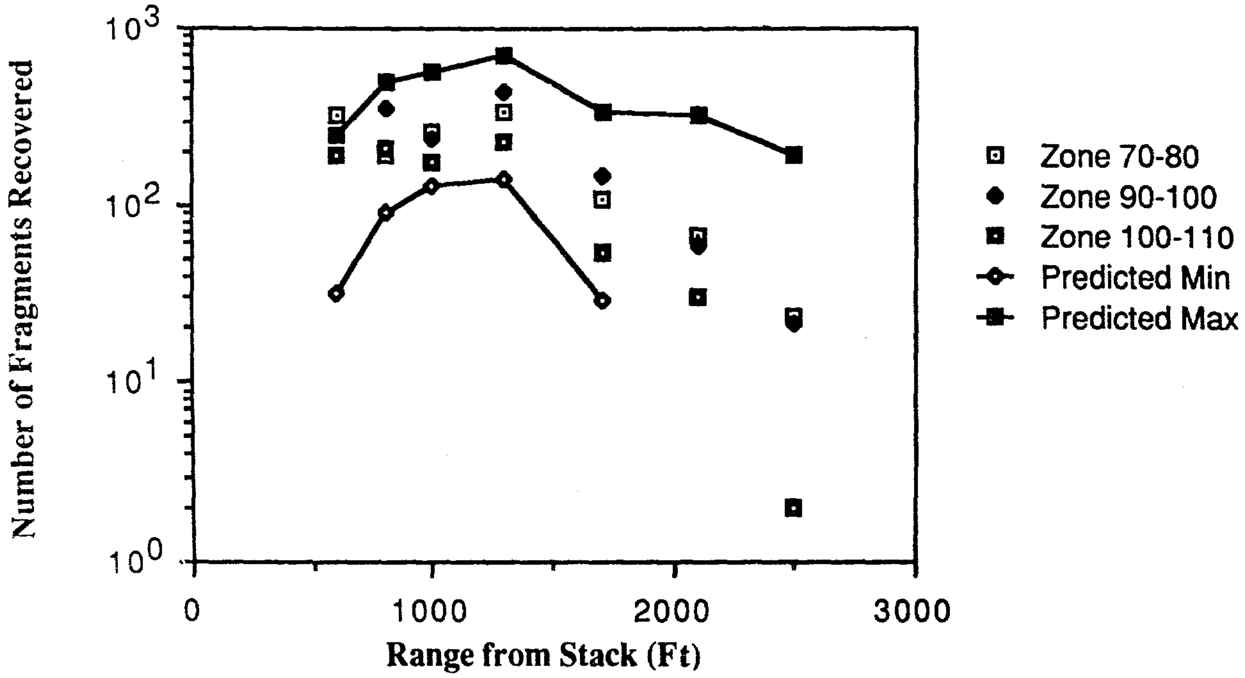


FIGURE 5. ACTUAL VERSUS PREDICTED RECOVERY DATA FOR 36 PALLETS OF 155MM PROJECTILES

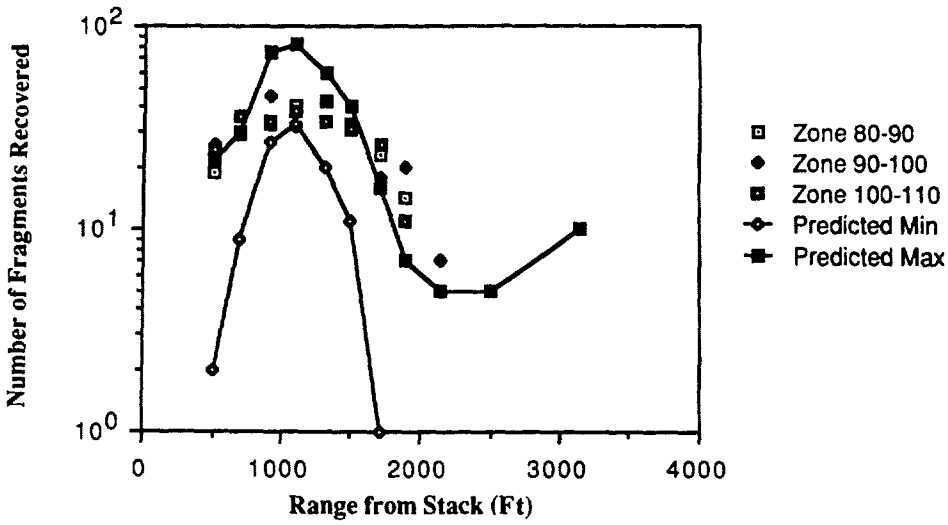


FIGURE 6. ACTUAL VERSUS PREDICTED RECOVERY DATA FOR A SINGLE PALLET OF MK 82 BOMBS

TABLE 2. NUMBER OF UNITS REQUIRED TO JUST EXCEED THE HAZARD DENSITY CRITERION

Range	Minimum	90%	50%	Maximum
50		0.12		
150		0.24		
250		0.43		
350		0.62		
450		2.31		
550		5.16		
650		8.14		
750		12.72		
850		~~27.35~~		
950		20.41		
1050		34.63		
1150		53.12		
1250		~~69.17~~		
1350		~~102.61~~		
1450		~~94.83~~		
1550		67.73		
1650		~~108.12~~		
1750		84.73		
1850		150.71		
1950		~~230.63~~		
2050		214.91		
2150		335.26		
2250		999999.00		
2350		999999.00		

Note that the range (distance) is given as the midpoint of each 100-ft hazard segment and is ready for plotting. Four columns of data are provided, one each for the minimum, selected percentile, 50th percentile, and maximum number of units required to just exceed the hazard density criterion. From a practical standpoint, each column of numbers can present a problem of interpretation. For example, the entry at 850 ft is 27.35 and the entry at 950 ft is 20.41. This leads to a contradiction from a safety standpoint even though the entries are quite plausible. The lesser number of units required at the greater range implies that when we add units to a stack, the hazard range can decrease. Since 20.41 is contained in 27.35, the 20.41 number should predominate and the 27.35 point should be eliminated. A systematic way of going about point elimination is to start at the top of the table and go down point by point. At each point, look back and if any previous points are equal to or greater than the point you are at then eliminate those points. Continue down in this way until you run out of points or all succeeding points are 999999.00. The 999999.00 points indicate no hazard; that is, no hazardous fragments are in those 100-ft hazard segments. When you are finished, you should have a set of points that are constantly getting bigger with range. Figure 7 shows both retained and eliminated points plotted versus hazard distance. If lines are drawn connecting the retained points, we form an upper bound. This upper bound can be somewhat erratic owing to the uncertain input data and the many non-linear relationships associated with trajectory calculations. A regression curve may be calculated using the retained points. A practical equation form for regression is:

$$R = A_1 + A_2 \ln N + A_3 \ln^2 N$$

where

R	=	Range or distance
N	=	Number of units required
ln	=	Natural log
A_1 A_2 A_3	=	Constants determined by regression

A regression program listing is contained in Appendix A. Figure 7 shows the regression curve for the retained points in Table 2.

SUMMARY

The FRAGHAZ computer model provides a flexible tool for predicting the fragment hazards of stacks of ammunition. The program has the inherent capability of considering the multidimensional problem posed by fragmentation hazards. The program has more than 200 variables. Its modular characteristics make it relatively easy to modify for specific problems like barricade effectiveness and public traffic route studies. The essential characteristics of the program are as follows:

- MONTE CARLO and FULL FACTORIAL options
- Individual three-dimensional fragment trajectories
- Two-dimensional wind vectors (horizontal plane)
- Fourth order Runge-Kutta trajectory calculations
- Fragment ricochet included
- Incorporates three-dimensional targets
- Can use different hazard criteria
- Air density and sound speed a function of altitude
- Storage sites may be at different altitudes
- Drag coefficient a function of the fragment presented area ratio and Mach number
- Predicts distribution of final fragment impacts in the ground plane
- Predicts hazard density, and probability of hit as a function of range for different hazard levels (MIN, PCT, 50th PCT, MAX)
- Predicts hazard distance values for different hazard levels (MIN, PCT, 50th PCT, MAX) as a function of number of units required in terms of two hazard criteria, density and probability of hit

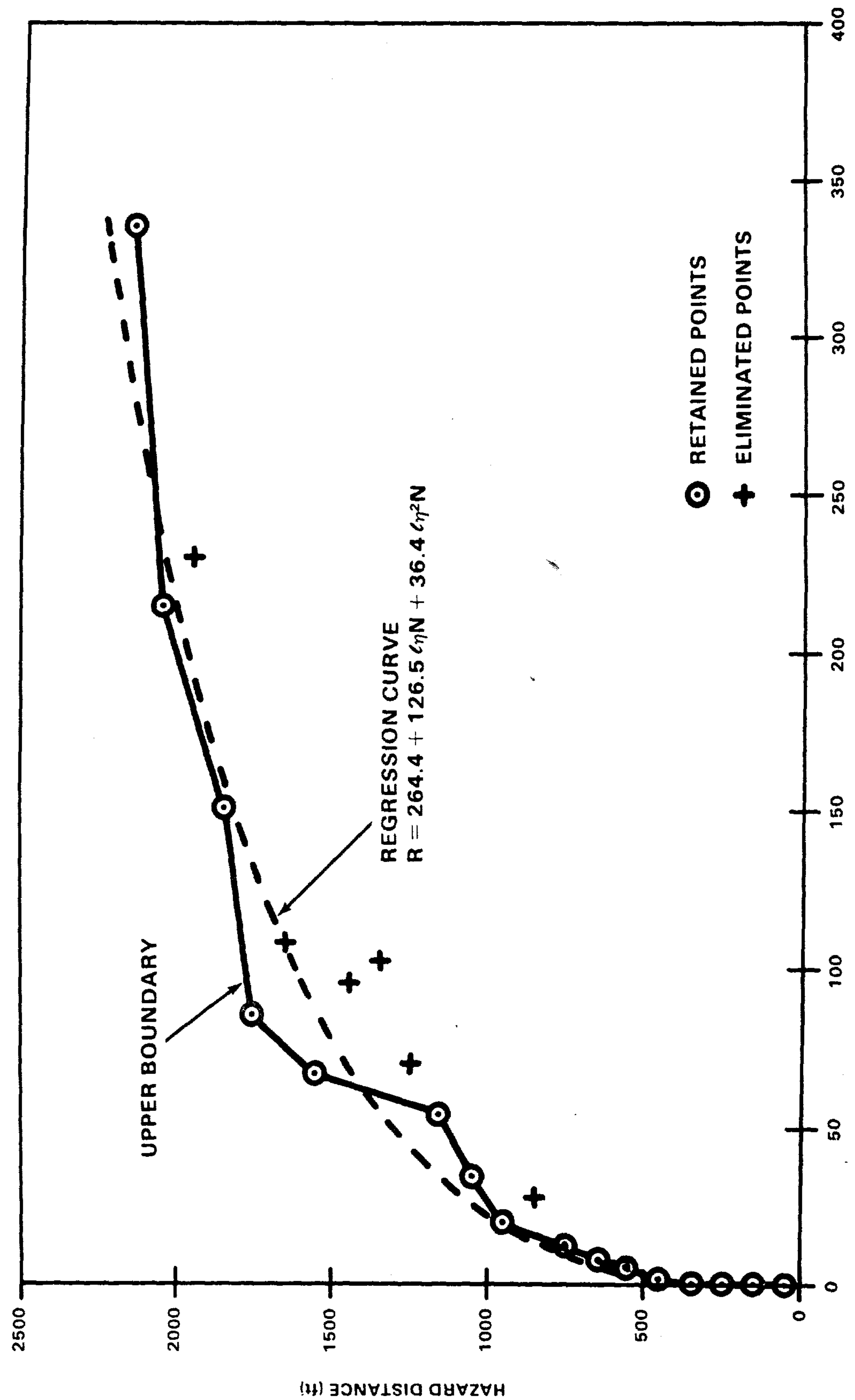


FIGURE 7. NUMBER OF UNITS TO JUST EXCEED HAZARD CRITERION VERSUS HAZARD DISTANCE

DETAILED PROGRAM DESCRIPTION

INTRODUCTION

The FRAGHAZ program has been coded in Microsoft FORTRAN 77 for use with the IBM PC-AT. The Program Listing is contained in Appendix B. The variables are defined in Appendix C.

Although INPUT and OUTPUT may be in different units, all calculations within the program are made in terms of pounds-feet-seconds. Radians are used for all trigonometric functions and arc length functions.

The program is divided into 26 blocks with block 21 divided into three sub-blocks. The discussion that follows will describe the program block by block and line by line where necessary.

Lines 1-7

The first 7 lines of the program are reserved for the program title and any general remarks that seem appropriate. The command, $LARGE, insures efficient handling of large arrays by the compiler. The command, $DEBUG, insures that if an error occurs in the running program, the line number at which the error occurs will be included in the error message.

BLOCK-1. DECLARE DATA TYPES FOR VARIABLES, DIMENSION ARRAYS

The variables are divided by type into REAL, INTEGER, DOUBLE PRECISION, and CHARACTER. All DOUBLE PRECISION variables begin with the letter U. The U variables are listed in Block 25, the function subprogram to calculate random numbers. Two variables (XE and XD) not listed in Block 1 are listed in Block 26, subroutine INTSTP, which calculates the displacement integration step for the Runge-Kutta routine. All variables are defined in Appendix C.

Block 1 also assigns values to constants that do not change from run to run. Values are also given for constants that may change from run to run. For example, the height (HM), width (WM), and depth (DM) measurements for the target will change when a different target is used. The measurements shown are for an average male soldier[2] approximated by a rectangular parallelepiped.

BLOCK-2. VARIABLES TO BE INPUT AT RUN TIME-SELECT MONTE CARLO OR FULL FACTORIAL OPTION

The variables are entered on the monitor screen in answer to the WRITE prompt statements. The variables are sent to memory by the READ statements. The user may want to READ the variables from a disk data file, but this will require editing the data file repeatedly when running a variety of input combinations.

Lines 86-89

The Frag Data File name is entered and used later to input all necessary frag data. The file name is contained in the character variable called Q.

[2]Castard, G. H. et al, *Evaluation of Explosive Safety Criteria*, AD871194, May 1970.

Lines 90-91

The output file name designates the printer for all output data. The designation is LPT 1 and is contained in the character variable called NAM.

Lines 92-93

Only one target per run is allowed. The target description is contained in the character variable TS. The height, width, and depth measurements in BLOCK 1, lines 78 and 79 should be consistent with the target description.

Lines 94-97

The minimum and maximum soil constants are entered here. This is one of the random variables. If a constant soil constant is desired, then enter this value for both the minimum and maximum values. The soil constant affects the ricochet angle and velocity. It also determines the critical ricochet angle above which the fragment will not ricochet. Soil constants for various soils and ricochet equations are presented in Appendix E.

Lines 98-101

The height of the ammo stack and the stack inert ground standoff being simulated are entered here. Individual fragment heights of origin (HO) will be selected from between these two values. The stack height (HS) and stack inert ground standoff (SIGS) are depicted in Figure 8. The height of origin is a random variable. For a constant HO, enter the desired constant height for both HS and SIGS.

Lines 102-103

The number of interaction areas or units on the face of the ammo stack towards the target area is entered here.

Lines 104-105

The number of fragment multipliers is entered here. There will be one multiplier for each polar zone used in describing the fragmentation. The multiplier is the effective number of fragments for one interaction area (unit) and 1 deg of azimuth as defined by the small scale fragment arena test. Since ricochet occurs at incident angles less than 20 deg, polar zones need only cover the range of 0 to 110 deg. Normally the upper limit has been 130 deg to cover possible future changes in the maximum ricochet angle. The derivation of fragment multipliers is explained in Appendix D.

Lines 106-107

The number of fragments to be used in the simulation is entered here. Usually all fragments greater than 300 grains are used. The number of fragments includes all fragments recovered in the small scale arena tests between specified azimuthal limits.

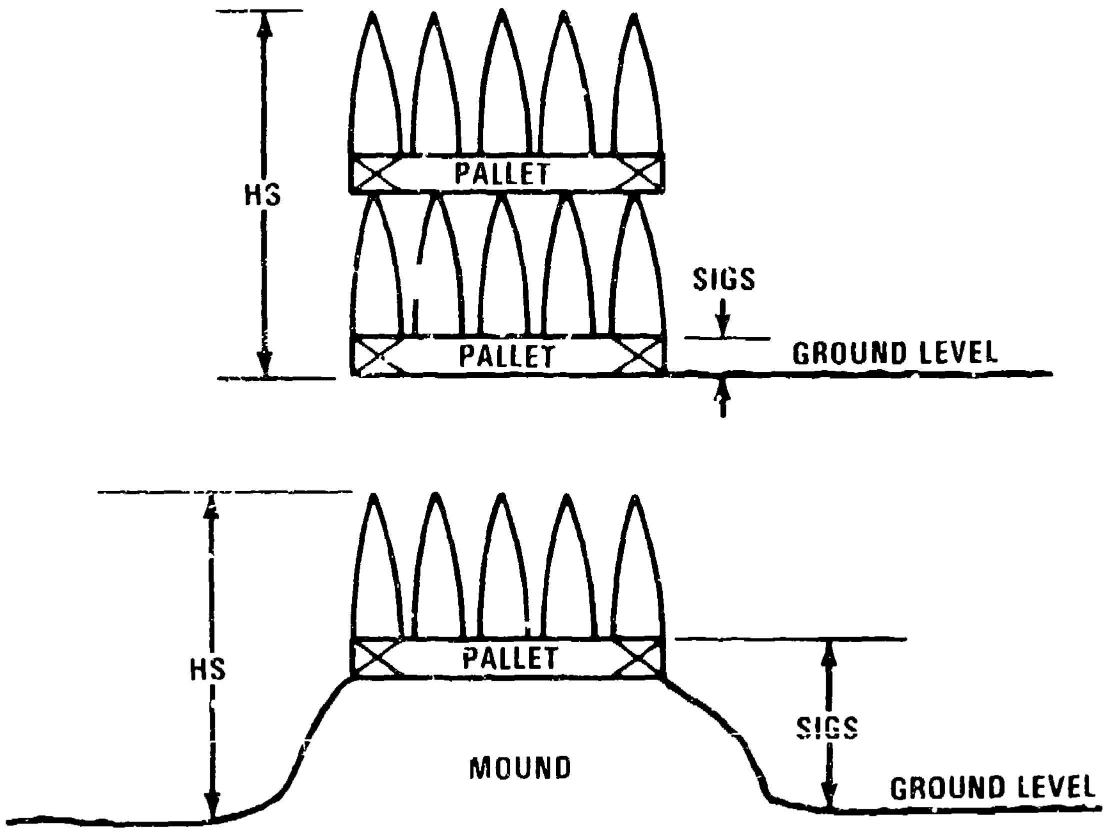


FIGURE 8. STACK HEIGHT (HS) AND STACK INERT GROUND STANDOFF (SIGS)

Lines 108-110

The percentile criterion to be used in the output tables is entered here. The percentile may be looked at as the level below which the percent (percentile expressed as a percent) of occurrences takes place. For example, a 90th percentile level would be that level at which 90 percent of the occurrences have already taken place. Another way of looking at a 90th percentile level would be to say that on an average only 10 percent of the occurrences will be greater than the 90th percentile level. The variable PCTD is in decimal notation which will be used in all calculations.

Lines 111-119

The MONTE CARLO or FULL FACTORIAL option is selected here. The flag RZ determines the appropriate path to be followed in the program.

If the MONTE CARLO option has been selected, then the number of replication is entered in lines 115 and 116.

Regardless of which option is selected the number of replications or treatments for which trajectory data is to be printed is entered in lines 117 and 119. This means that the initial and final conditions for each fragment trajectory will be printed for as many replications or treatments selected here. See test case output in Appendix II.

Lines 120-123

The maximum and minimum altitude of sites being simulated is entered here. This is one of the random variables. If a constant altitude is desired then enter this value for both the maximum and minimum values. The altitudes can be positive or negative depending on the site or sites being above or below sea level.

Lines 124-127

The maximum and minimum wind speeds are entered here. This is another of the random variables. If a constant wind speed is desired then enter this value for both the maximum and minimum values.

Lines 128-131

Wind direction is entered here. The wind direction is measured clockwise from the X-Y plane as shown in Figure 9. A tail wind is 0 deg. For practical hazard calculations, only a tail wind has been used to date. If a crosswind component is used, then fragments need not remain in the 10 deg hazard volume, and changes to the program may have to be addressed. Wind is always in a horizontal plane parallel to the ground plane at the current point of trajectory calculation. DW retains the wind direction in deg; WD is then changed to radians for calculations.

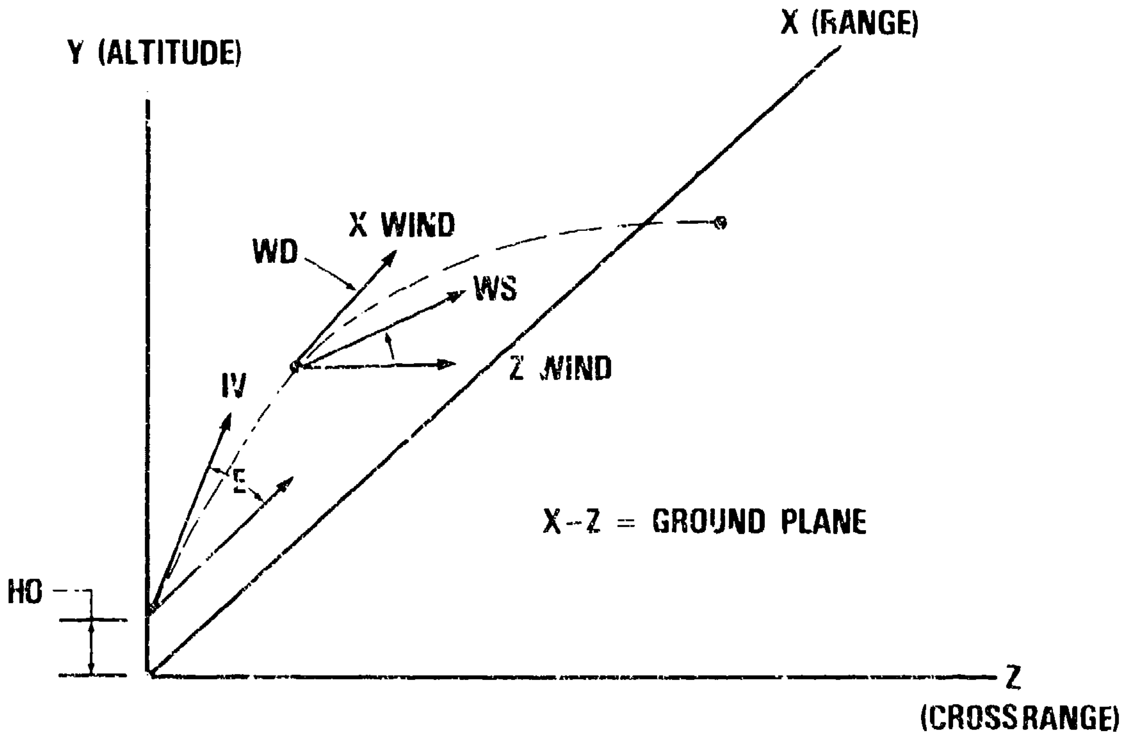


FIGURE 9 TRAJECTORY COORDINATE SYSTEM

Lines 132-135

The maximum computation range is entered here. To make all the output tables cover the desired range, the maximum computation range should be a multiple of 1200 ft. If the user selects too small a range, then the number of all fragments exceeding this range will be collected in a single memory location (TJ) and printed out. If TJ is greater than 0, then the user can rerun at a greater maximum computation range. Increasing the computation range does not significantly increase the running time for the program, it only increases the amount of paper used in the output tables. Following the input of the maximum computation range, a trap is provided to round the range to an even hundreds value. The new variable (MR) will be used in all calculations.

Lines 136-137

The hazard kinetic energy criterion is entered here. Currently this value is [illegible] ft-lbs. If another type of hazard criterion is to be used then the hazard calculation in line 605 (BLOCK 18) will have to be changed to reflect the new hazard type. For example, momentum, energy density, etc might be used. For an upper bound; that is, all fragments considered hazardous, enter zero for the kinetic energy criterion.

Lines 138-139

The hazard density criterion is entered here. Currently this value is one fragment per 600 ft^2 (0.0016667) for personnel. For any other target the criterion will be 1/(100 A) where A, in ft^2, is a single characteristic value for the presented area of the target; e.g., average, maximum, etc. These density criteria correspond to an expected probability of hit of 0.01.

Lines 140-141

The hazard probability of hit criterion is entered here. To be compatible with the hazard density criterion, the value is currently set at 0.01. Changing targets does not affect this value. The probability of hit criterion includes the actual presented area of the target in the plane perpendicular to each trajectory while the hazard density criterion does not.

Lines 142-145

If the MONTE CARLO option is selected, then the random number generator seed is entered here. The seed variable (USE) is a double precision integer variable varying from 1 to 2147483646. The random number generator used in this program is quite portable; that is, it will produce the same string of random variables for a given seed on almost all computers. This permits the use of the same MONTE CARLO checkout procedure for many of the users with different computers. Additionally, it provides the capability of running the same MONTE CARLO problem by different users with different computers. Appendix F contains a description of the random number generator and a program listing, which the user can use to determine whether his computer will produce the same results with the portable generator.

Lines 147-148

Line 147 is a prompt to tell the user to insert the disk containing the appropriate fragmentation data designated by the file name entered previously in lines 86-89. For example the file name for 155mm projectiles is FFRG155M. After inserting the data disk, the user presses "ENTER" and the program continues.

Line 149

The program begins running and prints "FRAGHAZ RUNNING" on the screen to let the user know that the sequence has begun.

BLOCK-3. PRINT ALL ESSENTIAL CONDITIONS FOR RUN

Line 154

In line 154, the printer port (1) is open to direct all output to the printer.

Lines 155-177 and 184-199

These lines write to the printer all conditions affecting the run. Most of the lines write the data input in BLOCK-2.

Lines 178-183

These lines print the seed selected for the MONTE CARLO option and then with the variable Y calls the random number generator to produce the first random number from the seed. The random number contained in Y is not used. From here on, each random number is produced with the call RND (UDUM)

BLOCK-4. HEADINGS AND NUMBER FORMATS FOR OUTPUT TABLES

Lines 204-233

These are the headings and number formats in FORTRAN notation that will accompany the output tables. They should be familiar to a user versed in FORTRAN 77.

BLOCK-5. READ FRAGMENTATION DATA. IF APPLICABLE, READ FULL FACTORIAL DATA

Line 239

The fragmentation data file port (2) is open prior to reading the data in lines 240, 247, and 262, if the FULL FACTORIAL option has been selected

Lines 240-245

There are three parts to the fragmentation data contained on the fragmentation data disk. The first part is the fragmentation multipliers, usually 13, to cover the polar zone range from 0 to 130 deg and the complimentary elevation angle range from −40 to +90. The second part of the fragmentation data contains five variable characteristics for defining the initial conditions for each fragment. The above two parts pertain equally to the MONTE CARLO and FULL FACTORIAL options. The third part contains the levels for each random variable to be used with the FULL FACTORIAL option only.

The fragmentation multipliers are read in line 240 and then printed out in line 242. In lines 243-245, the multipliers are multiplied by the Azimuth Sector size (AS), usually 10 deg. Remember that the fragment multipliers are for one unit and one deg of azimuth as explained in Appendix D. Multiplication by the number of units specified in the input will take place later in BLOCK-18, line 584.

Lines 246-250

The five variables defining the essential characteristics for each fragment are read here. The five variables are: Polar Zone Upper Limit, Fragment Weight, Area to Mass Ratio, Average Initial Velocity, and Maximum to Average Presented Area Ratio. In lines 248-249, the elevation angle defining the elevation zone is calculated. For example, a polar angle (PA) of 30 deg would define the polar zone 20 to 30 deg. The complimentary elevation angle is equal to (90-PA), and in this case, would be 60 deg defining the elevation zone 60 to 70 deg. Likewise, a 120 deg polar angle would define the polar zone 110 to 120 deg and the complimentary elevation zone of −30 to −20 deg. Elevation angles are with respect to the horizontal, positive upwards, and negative downwards. A positive initial elevation angle is shown in Figure 9. The variables IE (F) and AE (F) are saved in deg for later use.

Lines 251-271

These lines apply only if the FULL FACTORIAL option has been selected (Option Flag RZ=0). In line 252 the heading "FACTOR LEVELS" is printed. In lines 253 to 259,the names of the seven random variables are assigned to the character array variable (H9). The reading of the levels for each random variable takes place in line 262. Note that the READ statement stipulates that on error go to 1128 (line 263). The last entry for the factor levels is a letter which causes an error in the READ statement that finishes the number of factor levels for that random variable. While reading each factor level, a count is kept in (NL (I)). When all factor levels are read, the number of treatments is calculated in line 266 as the product of the number of factor levels for each random variable. Note that the variable NR is used for the number of treatments,the same variable used for the number of replications in the MONTE CARLO option. As far as the FRAGHAZ program is concerned, the two options differ only in the manner in which the initial conditions are selected for each fragment. Lines 267-269 constitute a trap to stop the program if the number of treatments is greater than 100. If the user needs more than 100 treatments or replications, then the array variables (D6H), (PX) and (YN) will have to be redimensioned in BLOCK-1 by changing the first element of each from 100 to the desired maximum number of treatments or replications desired.

Line 272

The fragmentation data file is closed here. At this point all necessary fragmentation data have been read.

Lines 273-279

The number of treatments or replications and the number of treatments or replications to be printed are printed out here depending upon the value of option flag (RZ). The number of treatments or replications to be printed means that the initial and final conditions for each fragment trajectory will be printed out for as many treatments or replications specified. This output is good for making spot checks to insure that the FRAGHAZ program is running as intended.

BLOCK-6. BEGIN REPLICATION OR TREATMENT LOOP-SET CONDITIONS

Line 284

The maximum range variable (MR) is expressed in hundreds of feet.

Lines 289-293

The probability of not hitting the target (PX (T, R)) is initialized for all replications or treatments and for each 100-ft range increment. The null value is one because the variable is the probability of not hitting the target. The probability of hitting the target is 1-PX (T, R).

Lines 295-296

The replication or treatment counter (T) is set back to zero in line 295 after its use in the previous DO loop. In line 296, the flag RZ determines whether we will follow the MONTE CARLO or FULL FACTORIAL option in controlling the replication or treatment loop.

Lines 297-299

If the MONTE CARLO option has been chosen then the replication counter is incremented in line 297. The loop will be complete when the IF statement in line 298 is satisfied. The return terminal point for the replication loop is line 709. When the IF statement in line 298 is satisfied we go to 3570 (line 718) and start the SORT routines which follow the completion of all trajectory calculations.

Lines 301-322

This is the treatment control loop used when the FULL FACTORIAL option is chosen. It is controlled with GOTO statements. Variables F1 thru F7 correspond to the seven random variables named in lines 253-259. The array variables NL(1) thru NL(7) contain the number of levels associated with each of the seven random variables. For the first treatment, all variables are set to their first level and the treatment counter (T) is incremented in line 322. Note that the treatment counter is the same as that used to count MONTE CARLO replications. When this treatment is completed, the program is returned to 1169 (line 320) by the GOTO statement in line 711. At 1169 (line 320), F7 is incremented. This continues until F7 is greater than NL(7) at which time we GOTO 1168 (line 317). In line 317, variable F6 is incremented to its second value and F7 is returned to 0 and then incremented to its original first value. We then increment thru F7 again until F7 is greater than NL(7). In this way we work up the ladder and produce all the combinations for the factor levels of the seven random variables. Ultimately we get to the point where all combinations (treatments) have been run and satisfy the IF statement in line 303. At this point we GOTO 3570 (line 718) and start the SORT routines which follow the completion of all trajectory calculations.

Lines 324-335

Here we calculate the values for the soil constant, altitude, and wind speed for each replication or treatment. Factor levels are used in establishing the values of the three random variables when the FULL FACTORIAL option is selected. When the MONTE CARLO option (RZ = 1) is selected, random uniform numbers between zero and one are used by calling the RND function with RND (UDUM). In either case, if we had entered the same value for the maximum and minimum values of any of the three random variables, then the random variable would remain constant at this value over all replications or treatments.

Lines 337-343

Here we set the loop variable (XL) and the flag (EZ) which will be used in the Runge-Kutta routine, lines 528 and 520. When there is no cross-range component of wind, XL = 4 and EZ = 0, then all calculations will be in the X-Y plane only. When there is a cross-range component, then trajectory calculation will also be made in the Z (cross-range) direction (XL = 6 and EZ = 1).

Lines 345-348

The soil constant, altitude, and wind speed are printed out at the top of the trajectory tables in lines 345 and 346. We change to a compressed mode of about 17 characters per in. for the trajectory table heading and the actual trajectory values with the printer call in line 347. The heading for the trajectory table is printed in line 348. An explanation of the heading elements is given in Appendix H.

Lines 349-353

The average total and hazardous probabilities of not hitting the target are initialized to one at the beginning of each replication or treatment. These variables will be used in calculating the average probability of not hitting the target.

BLOCK-7. BEGIN FRAGMENT LOOP-SET HEIGHT OF ORIGIN AND ELEVATION ANGLE

Line 358

The fragment loop begins here. We will calculate trajectories and accumulate statistics for each fragment in each replication or treatment.

Line 359

The number of rebounds (ricochets) is set to zero at the beginning of each trajectory calculation.

Lines 360-368

The random variables (HO-Height of Origin) and (E-Elevation Angle) are set for each fragment trajectory. The procedure is accomplished with a Factor Level for the FULL FACTORIAL option (RZ = 0) or with a Uniform Random Number (zero to one) for the MONTE CARLO option. Note that if the same value has been input for the HS and the SIGS then HO will be constant for all fragment trajectories and all replications or treatments. The variable HO is shown in Figure 9. The variable ES is the elevation zone size, normally 10 deg. As such, the uncertainty in the elevation angle is also 10 deg. Note we divide by (B) to express (E) in radians for trajectory calculations. Two variables (XE) and (YE) are expressed in deg for later use.

Lines 370-374

Here the flag (CY) is set to one if HO is greater or equal to the target height (HM), which means that the fragment starts at the top or above the hazard volume. The flag is set to zero if the fragment starts within the hazard volume. This flag is used in conjunction with the flag (CX) to determine the range at which the fragment pierces the roof of the hazard volume when coming from below. The use of this flag will be discussed in detail in BLOCK-17.

BLOCK-8. SET REMAINING INITIAL CONDITIONS FOR CURRENT FRAGMENT

Line 379

The variable (FG) is defined and will be used in calculating the kinetic energy of the fragment in line 605.

Line 380

The variable (RL-Range Last) is set to zero. This variable is used to determine when a fragment trajectory passes from one 100-ft increment to another in the hazard volume. A number of variables must be reset when this occurs (see lines 562 to 578). The variable (RL) is expressed in hundreds of ft to be compatible with the variable (R). For example, when (R) or (RL) equals 7 we know we are dealing with the 600 to 700-ft range increment.

Lines 382-394

Here we prevent the elevation angle from being 0 or 90 deg. Such values would cause trouble later when we must make calculations using the sine and tangent of the elevation angle. The highest positive elevation permitted is 89.99 deg. The lowest positive elevation angle permitted is 0.01 deg. The highest negative elevation angle permitted is -0.01 deg.

Line 395

Here we call the Integration Step Subroutine (BLOCK-26). Although the Runge-Kutta routine will use a time step, using a displacement step can, under certain conditions, speed up the program by a factor of 10. The displacement step is converted to a time step by dividing it by the current magnitude of the fragment velocity vector. Details of the displacement step will be explained when we get to BLOCK-26.

Lines 397-407

The value of fragment initial velocity is computed here. This is one of the random variables. From experience, the approximate error in measuring average initial velocity for a polar zone is between plus and minus seven percent of the measured velocity. This is due to instrumentation error. The error is assumed to fit a normal distribution with one sigma equal to three and one-half percent of the measured average velocity. For the FULL FACTORIAL option (RZ = 0), the velocity factor levels are expressed in sigmas. For the MONTE CARLO option (RZ = 1) we make use of a Standard Normal Random Number generator (lines 400-403) with a mean of zero and a variance of one. This generator which uses two Uniform Random Numbers (zero to 1) and produces two Standard Normal Random Numbers (N1 and N2) has been described in the literature.[3] Again one sigma is taken as three and one-half percent of the measured average velocity for the polar zone. Note that only N1 is used. N2 is a spare for possible future use. Finally, the value of initial velocity for the fragment is saved in variable (XV) for output in the trajectory tables.

[3]Box, G. E. P. and Muller, M. E., *A Note on the Generation of Random Normal Deviates*, Analysis of Mathematical Statistics, (1958) Vol. 29, pp 610-611.

BLOCK-9. ESTABLISH DRAG PARAMETERS

Lines 412-421

Here we calculate the anchor point (D1) and three pivot points (D2, D3, D4), which will be used in BLOCK-14 to produce the straight line approximations to the drag curve. The state of knowledge concerning drag for irregular fragments is such that a complicated curve cannot be justified. Each fragment in each replication or treatment has its own drag curve approximation depending on its maximum to average presented area ratio. The drag coefficient is a sensitive parameter. The low subsonic drag coefficient can vary from 0.5 to 1.5 depending on the shape of the irregular fragment. Going from 1.5 to 0.5, the drag coefficient for a typical far-field trajectory can produce a doubling of range.

The drag coefficients used in the FRAGHAZ program were derived by tests in a vertical wind tunnel.[4] Ninety-six fragments were tested by controlling the vertical air stream until the fragment was suspended in vertical equilibrium. At this point, the drag coefficient can be calculated as shown in Figure 10 because the drag force and the weight (W) of the fragment are equal. The velocity (V) and the density of the air (ρ) are measured at the time of vertical equilibrium. For these tests the characteristic area (A) was the average presented area of the fragment in all cases. The equation at the bottom of Figure 10 is applied with appropriate units to make C_D dimensionless.

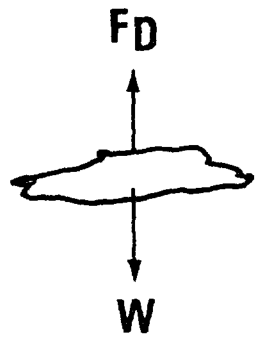
Since C_D is dimensionless, any correlating parameters must also be dimensionless. A great number of dimensionless ratios were attempted. These were based on linear, area, perimeter, variances, and moments of inertia. The best correlation was obtained with the dimensionless ratio-Maximum to Average Presented Area. The results for all 96 fragments are shown in Figure 11. The upper and lower limits of uncertainty are shown as straight lines which are used to calculate specific values of the low subsonic C_D for either the MONTE CARLO or FULL FACTORIAL option. Since each C_D for each of the 96 fragments tested applies only to the velocity (Mach Number) recorded when the fragment was suspended in vertical equilibrium, we have only one point on the drag curve. In the tests, the Mach Numbers were approximately 0.1. These C_D values are used as anchor points for constructing the straight line approximations to the C_D curves for irregular fragments having given maximum to average presented area ratios. Note that Figure 11 applies to fragments of any material because C_D is a function of shape only (including surface roughness).

For the vertical wind tunnel tests, three regular fragments were used as a check on the data presented in an earlier report on fragment drag coefficients.[5] The three regular fragments were a sphere, cube and a bar ($1\frac{1}{4} \times \frac{1}{4} \times \frac{1}{4}$ in.). In the Dunn and Porter report, values of C_D for these fragments were given at a Mach number of about 0.75. When these values were compared, the following relation was observed:

	C_D ($M \approx 0.1$) Wind Tunnel	C_D ($M \approx 0.75$) Dunn and Porter	Difference
Sphere	0.42	0.60	+0.18
Cube	0.64	0.88	+0.24
Bar	0.94	1.12	+0.18

[4]McCleskey, Frank, Drag Coefficients for Irregular Fragments, Naval Surface Warfare Center, TR 87-89, February 1988.

[5]Dunn, D. J. Jr., and Porter, W. R., *Air Drag Measurements of Fragments*, BRL memorandum Report No. 915, August 1955 (UNCLASSIFIED).



VERTICAL EQUILIBRIUM

$$F_D = \text{DRAG FORCE} = \frac{C_D \rho A V^2}{2}$$

$$W = \text{FRAG WEIGHT}$$

$$F_D = W = \frac{C_D \rho A V^2}{2}$$

$$\boxed{C_D = \frac{2W}{\rho A V^2}}$$

FIGURE 10. EXPERIMENTAL DRAG COEFFICIENT

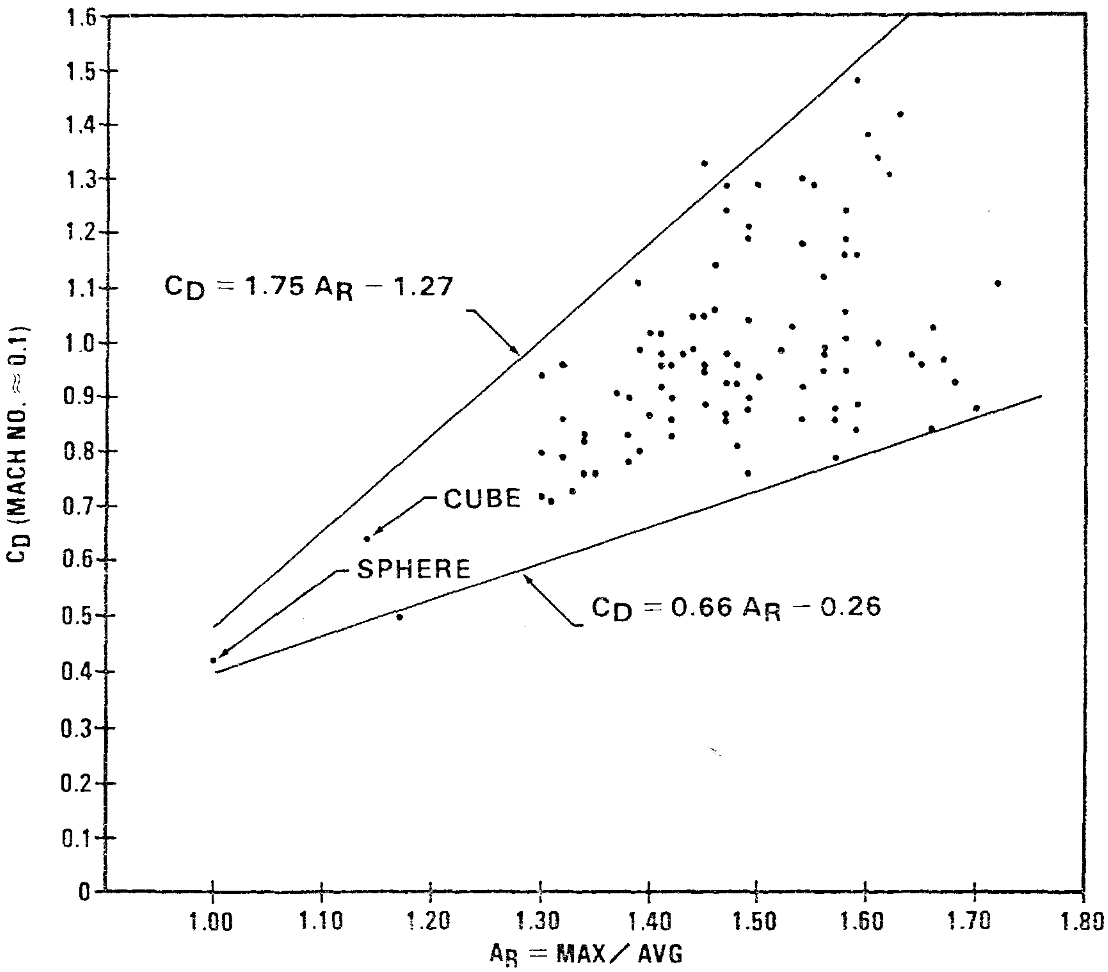


FIGURE 11. DRAG COEFFICIENT (C_D) VS. PRESENTED AREA RATIO (A_R)

Owing to the consistency of the differences, we have chosen to designate the first pivot point at Mach Number 0.75 with a C_D 0.2 larger than the C_D at Mach Number 0.1. As such, we have a reasonably good approximation to the shape of the subsonic drag curve. This is important because about 75 percent of the range for a typical far-field fragment is traveled at subsonic velocities.

The remainder of the straight line approximations to the drag curve for each fragment are shown in Figure 12. The level of the straight line approximation is totally dependent on the anchor point (D1) value selected from Figure 11 for any particular fragment. Each pivot point is determined by adding a constant value to the value of C_D for the anchor point. The constant values for determining pivot points two and three are approximations based on the study of data contained in two reports.[5,6] These data were quite scattered. Note in Figure 12 that the C_D above Mach Number 2.5 is constant at the value designated at the Mach Number 2.5 pivot point.

[6]Daniels, et al., *Subsonic, Transonic and Supersonic Drag Characteristics of Nine Shape Categories of Warhead Fragments*, NSWC TR 81-112, May 1981.

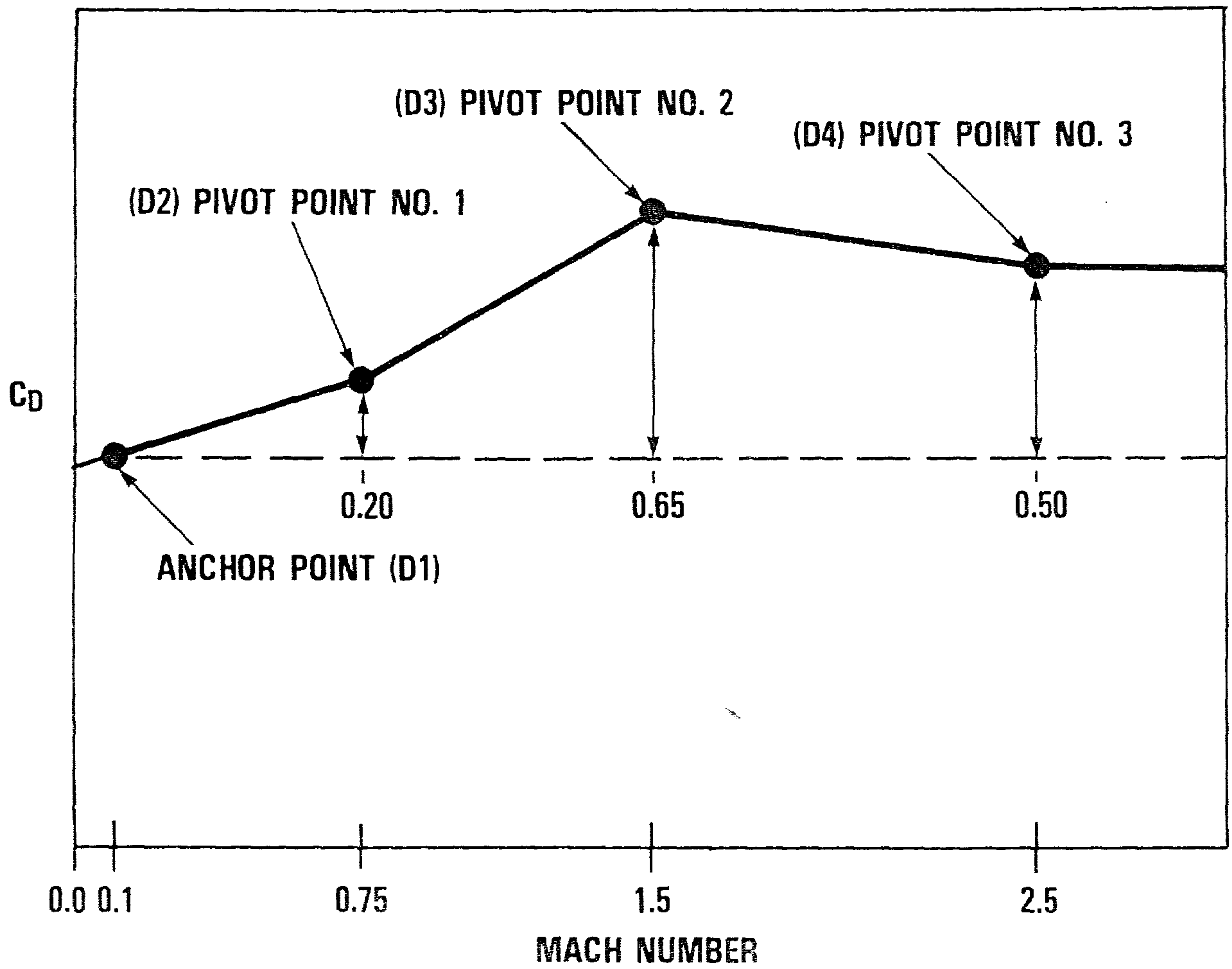
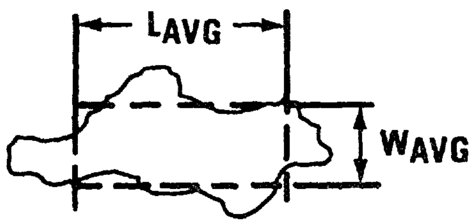


FIGURE 12. STRAIGHT LINE APPROXIMATION TO FRAGMENT C_D CURVES

To use Figure 11, we must be able to measure maximum and average presented area for any irregular fragment. This can be done with a gage such as the Icosahedron Gage. If a gage is not available or the fragment will not fit the gage, then a good approximation may be made using an equivalent volume and weight parallelepiped. First measure average length and width for the fragment as shown in Figure 13. Usually length is taken as the largest dimension and thickness the smallest. Then calculate average thickness using the equation given in Figure 13. With the average values for length, width and thickness, average presented area and maximum presented area can be computed using the equations shown in Figure 14.

Lines 412 and 413 contain straight line equations for the high (CH) and low (CL) limits of C_D uncertainty for a given maximum to average presented area ratio (AR2(F)). The uncertainty is shown in Figure 11. The area ratio is the last of the five quantities read from the data disk for each fragment. In lines 414-418, the specific value of C_D, at a Mach Number of approximately 0.1, is calculated for the FULL FACTORIAL option (RZ = 0) or the MONTE CARLO option (RZ = 1). For the FULL FACTORIAL option we use the current factor level for C_D. For the MONTE CARLO option we use a uniform random number (zero to one). The variable D1 is the anchor point in Figure 12.

AVERAGES



FOR EQUIVALENT WEIGHT AND VOLUME

$$T_{AVG} = \frac{WT}{L_{AVG} \cdot W_{AVG} \cdot \rho}$$

WT = FRAG WEIGHT (lb)

L_{AVG} = AVERAGE LENGTH (in.)

W_{AVG} = AVERAGE WIDTH (in.)

ρ = FRAG DENSITY (lb/in.^{3})

$\rho = 0.28$ (STEEL)

FIGURE 13. FRAGMENT AVERAGE LINEAR DIMENSIONS

Finally, in lines 419-421, we compute pivot points 2, 3, and 4 (D2, D3, D4) by applying the constant offsets to the anchor point shown in Figure 12.

The data calculated here will be used later in BLOCK-14 to calculate C_D as a function of Mach Number throughout the trajectory of each fragment.

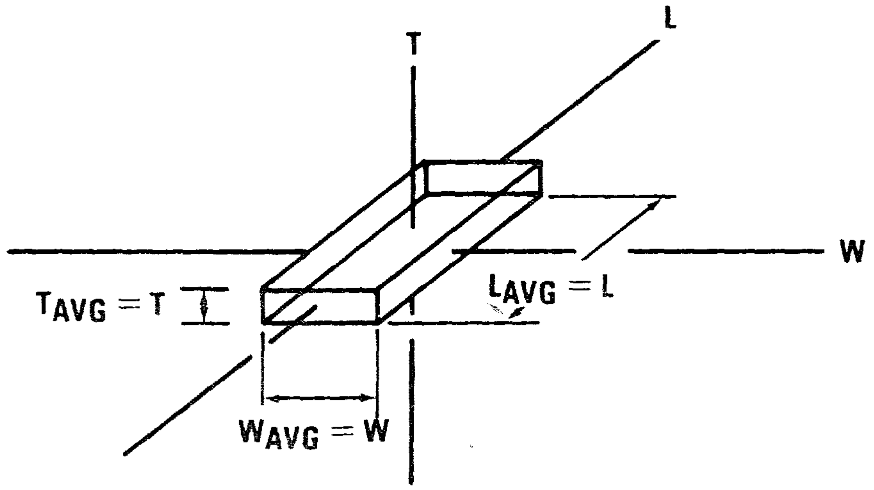
BLOCK-10. SET INITIAL CONDITIONS FOR FRAGMENT TRAJECTORY

<u>Lines 426-432</u>

The Runge-Kutta routine used to calculate a trajectory requires initial velocity and displacement conditions. The calculated velocity and displacement conditions at the next point require the velocity and displacement conditions at the current point. The displacement along the trajectory from point to point may be a matter of 4 in. or as large as 70 ft depending on conditions. The DI array variables are defined as follows:

DI (1) - Accumulates time of flight in seconds. Not part of the Runge-Kutta calculations
DI (2) - Range (X) component of velocity (ft/s)
DI (3) - Range (X) component of displacement (ft)
DI (4) - Altitude (Y) component of velocity (ft/s)
DI (5) - Altitude (Y) component of displacement (ft)
DI (6) - Cross-Range (Z) component of velocity(ft/s)
DI (7) - Cross-Range (Z) componentof displacement(ft)

(EQUIVALENT WEIGHT AND VOLUME RECTANGULAR PARALLELEPIPED)



AVERAGE $= 0.5\ (L \cdot W + L \cdot T + W \cdot T)$

MAXIMUM $= ((L \cdot W)^2 + (T \cdot L)^2 + (T \cdot W)^2)^{1/2}$ DOES THIS MAKE SENSE?

FIGURE 14. FRAGMENT PRESENTED AREA MEASUREMENTS

Note that even indices are for component velocities and odd indices are for component displacements. Since DI (6) and DI (7) are initially zero, the trajectory always begins in the X-Y plane. Only if a crosswind is specified, will there be crosswind components of velocity and displacement. Throughout the Runge-Kutta procedure, calculations from one point to the next will be made in terms of X, Y, and Z velocity and displacement components. To calculate the total velocity and displacement we use the square root of the sum of squares of the component values. Throughout the FRAGHAZ program there is no use of matrix algebra; all calculations with regards to vectors are made with straightforward trigonometric procedures. The signs for component velocities and displacements are as follows. Altitude (Y) component velocity (DI (4)) is positive when the trajectory is ascending and negative when the trajectory is descending. Range (X) and Cross-Range (Z) velocities (DI (2) and DI (6)) are always positive. Altitude (Y) displacement (DI (5)) is positive above ground level and negative below ground level. Range (X) and Cross Range (Z) displacements (DI (3) and DI (7)) are always positive. DI (4) and DI (5) will be used repeatedly to sense trajectory conditions. At this point we have completed the entry of all conditions necessary for the calculation of the first fragment trajectory.

BLOCK-11. BEGIN TRAJECTORY CALCULATIONS

Line 437

We compute the magnitude of the initial fragment velocity vector here. This is the point we will return to after completing the integration to the next point. We always start an increment knowing the velocity and displacement at the end of the previous increment. The velocity, modified by wind if applicable, is necessary for defining the component drag accelerations.

Line 438

This is the standard time increment of integration using the displacement increment obtained previously from BLOCK-26. This time increment may be replaced in BLOCK-12 depending on conditions.

Lines 439-440

Here we compute the last elevation angle (LE); that is, the one existing at the end of the last increment of integration. In line 440 we prevent this angle from becoming zero because of subsequent sine and tangent operations. This angle is used in linear predictions to control the trajectory in or near the pie-shaped Hazard Volume. Note how the X, Y, and Z components of velocity are used to calculate (LE), and that (LE) is an absolute value. The angle (LE) will be used in calculations which require a positive sign for the elevation angle (E). The elevation angle (E) is positive for an ascending trajectory and negative for a descending trajectory.

BLOCK-12. COMPUTE SPECIAL TIME INCREMENT IF CONDITIONS DICTATE

Lines 445-459

Here we compute special time steps when we are near or within the Hazard Volume. These calculations pertain only to a descending trajectory (DI (4) < 0). Ascending trajectories within the Hazard Volume will be addressed in BLOCK-17. In either case, we are determining an accurate range at which the trajectory pierces the top of the Hazard Volume or the ground plane as shown by the large dots in Figure 3. This is done so that we can accurately assign hazards to the proper 100-ft increment of the Hazard Volume.

We will start with line 452 where the altitude at the beginning of the current integration step is above the Hazard Volume. When the altitude (DI (5)) is less than XD + 12 then we make a linear prediction from the current point to the top of the Hazard Volume and compute a time increment which will bring us near, but above the top of the Hazard Volume. Lines 455 and 456 checks to see if the linear prediction is less than the height of the Hazard Volume (HM) and if so, computes a new time increment to bring us closer to the top of the Hazard Volume. The new time increment supercedes the previous one. After completing this integration step we are very close to the top of the Hazard Volume and the new linear prediction in lines 457-458 will be nearly coincident with the curved trajectory. We then compute a time increment which will bring us just below the top of the Hazard Volume, a matter of a fraction of an inch. We add two microseconds to this time increment to prevent having to make more than one step to place us just below the top of the Hazard Volume. The range at this point will tell us what 100-ft increment the trajectory first encounters so that we may properly designate hazard statistics.

Lines 446-451 do the same thing by taking the trajectory from just below the top of the Hazard Volume to a point just below ground; again a matter of a fraction of an inch. This will accurately define the range at which the fragment strikes the ground and either stops or ricochets. All of the calculated special time increments have been derived empirically by running thousands of trajectories.

Line 460

A special time delay (0.1 s) is assigned for high elevation trajectories to permit stable operation of the Runge-Kutta routine going around a tight turn at the top of the trajectory at very low velocities.

Line 461

A special time increment (0.08 s) is assigned after two or more ricochets have occurred and the fragment velocity has fallen below 150 ft/s. Again, this is to insure Runge-Kutta stability and accuracy.

Line 462

Finally, time of flight is accumulated in DI (1). Note that as we go down the list of special time increments, each one calculated will supercede all previously calculated time increments. If none of the special time increments apply, then the standard time increment in line 438 applies.

BLOCK-13. BEGIN RUNGE-KUTTA ROUTINE AND CALCULATE WIND EFFECTS

This begins the outer loop for the trajectory calculations. The constant (KM) is set (lines 468-472) and will be used in the calculation of the velocities in each component direction (line 535) for the fourth-order Runge-Kutta routine. In the outer loop, fragment velocity, air density, and drag coefficient must be updated before calculating the constants (XK (I, J)) in line 530.

Lines 473-491

Here we have three alternatives depending on the wind conditions. First (lines 473-476) we have the case for no wind and we need only make calculations for the X-Y plane. We calculate (VP), the total velocity of the fragment which will be used in calculating acceleration in line 515. The angles (AY) and (AX) will be used to calculate the X and Y components of acceleration in lines 516 and 518. The second alternative is given in lines 477 to 482. Here we have a tail wind (DW = 0) and we must include the wind velocity in the X-Y plane. Wind is in a horizontal plane and we need only be concerned with the X (Range) component. Again we compute (VP), (AY), and (AX) for use in the acceleration equations. The third alternative includes a cross-wind and we address this factor in lines 484-490. Since wind is in a horizontal plane we need only be concerned with adding its effects in the X and Z directions. Again we compute (VP), (AY), (AX), and also (AZ) for use in the acceleration equations. Remember that all calculations will be made in the component directions. Total velocity and displacement can be calculated at any time by using the square root of the sum of squares of the components.

BLOCK-14. CALCULATE AIR DENSITY, MACH NUMBER, AND CD

Lines 496-510

This part of the outer loop updates air density and the drag coefficient in the calculation of the four Runge-Kutta constants.

Air density is calculated in line 496 as a function of altitude (DI (5)). Actually, it is one-half the air density. The factor one-half is incorporated here rather than in the acceleration equation in line 515. The equation for air density is taken from a standard text.[8] Note that we add (DI (4) * DLT/2) to the altitude. We do this because in the Runge-Kutta routine we calculate the four constants of integration only from acceleration to velocity. We use three of these constants to calculate the component displacements directly. As such we do not have an updated altitude for calculating successive Runge-Kutta constants. We therefore put the altitude approximately between the starting and ending of the trajectory integration increment.

The Mach number equation (line 497) is taken from the text mentioned above and we add the same small altitude correction as we did for air density.

In lines 498-510 we calculate the drag coefficient as a function of Mach Number using the C_D points (D1, D2, D3, and D4) calculated in BLOCK-9. These equations represent straight line approximations to the drag curve shown in Figure 12. The drag coefficient is used in the acceleration equation in line 515.

BLOCK-15. CALCULATE VELOCITIES AND ACCELERATIONS

Lines 515-523

Line 515 is the total acceleration equation. It is nothing more than an application of the Newtonian equation: F = ma. In lines 516, 518, and 521 if applicable, we designate the X, Y and if applicable, the Z components of acceleration. Note the signs associated with these components and the fact that the acceleration due to gravity (G) is placed in the Y component of acceleration. The variables DO (3), DO (5), and DO (7) are not used in the Runge-Kutta calculations which follow but have been left here should the user want to make the integration from velocity to displacement by calculating an additional four Runge-Kutta constants.

BLOCK-16. BASIC RUNGE-KUTTA CALCULATIONS

Lines 528-537

There are many ways of coding a fourth-order Runge-Kutta procedure. The procedure here is described in a Numerical Analysis text.[9] This BLOCK constitutes the inner loop of the procedure. Note that we calculate only four constants XK (1,J), XK (2, J), XK (3, J), and XK (4, J), where the J's are 2, 4, and 6 representing the X,Y, and Z component directions. Component velocities at the end of the integration step are calculated in line 532. Component displacements are calculated in line 533 using the first three of the four Runge-Kutta constants. Using this technique, we can cut the running time substantially. The inner Runge-Kutta loop ends in line 537, the outer loop of the Runge-Kutta routine ends in line 538.

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[8]Morrison, R. B. and Ingle, M. J., *Design Data for Aeronautics and Astronautics*, John Wiley and Sons, Library of Congress Catalog Number 61-17267, p. 4, 1962.

[9]Scarborough, J.B. Phd., *Numerical Mathematical Analysis*, Sixth Edition, The Johns Hopkins Press, p. 361, 1966.

BLOCK-17. CHECK LOCATION OF FRAGMENT AND MAKE HAZARD VOLUME CALCULATIONS IF APPLICABLE

At this point, we have completed an integration increment and have the component velocities and displacements existing at the end of the increment. These values (DI (2) to DI (7)) were calculated in lines 532 and 533.

Lines 544-545

Here we compute the designator for the 100-ft range increment. For example, if the range were 738 ft then (R) would equal eight designating that the fragment was in the 700 to 800-ft range increment. Line 545 puts the fragment in the special range increment (MR + 1) if the fragment range is beyond the specified maximum calculation range. This fact will be shown in the variable (TJ) and will indicate in the output tables how many fragments exceeded the maximum calculation range so that we may increase the maximum calculation range for future runs.

Lines 546-560

Here we determine whether the fragment has pierced the top of the Hazard Volume from below. This will have occurred only if the unique combination of the flags CX and CY are CY = 0 and CX = 1, when we reach the ELSE statement in line 553. If line 553 is satisfied then we know that the end point of the increment is above the Hazard Volume and the starting point of the increment was below the top of the Hazard Volume. As such, we have pierced the top of the Hazard Volume from below. CY is immediately set to one to prevent subsequent consideration of piercing the top of the Hazard Volume until a ricochet may have occurred. CY is set back to zero in line 678 after a successful ricochet. CY is also initialized at the start of the trajectory in lines 370 to 374. In line 555, we calculate the difference in range from the end point of the increment to the point where the trajectory pierced the top of the Hazard Volume. A new range increment designator (R) is calculated which may be different than the designator (R) calculated in line 544. This procedure is different from the linear predictor procedure carried out in lines 445 to 459 to position increment end points just below the top of the Hazard Volume or the ground plane for descending trajectories. The difference is necessitated by the fact that as a trajectory progresses in the air the path of the trajectory is always curving downward; that is, diminishing elevation angle. Although a linear predictor might put the end point of the increment above the top of the Hazard Volume, the actual trajectory might just skim the underside of the top of the Hazard Volume.

If the fragment is below the top of the Hazard Volume, then lines 551 and 552 will direct us to the initializing block (lines 562-578) prior to entering BLOCK-18 where the basic output statistics are calculated. If the fragment is above the Hazard Volume and line 553 does not apply then we are directed to line 621 (5170) to begin the next increment.

Lines 562-578

If the 100-ft range increment designated by (R) for this current end point is different from the end point designator for the previous increment (RL) then we must initialize certain variables for BLOCK-18. If R = RL, then our current end point is in the same 100-ft increment as the previous end point and we proceed directly to BLOCK-18 to continue averaging hazard values for the 100-ft range increment.

BLOCK-18. ROUTINE FOR ACCUMULATING NUMBER OF FRAGMENTS, DENSITY, AND PROBABILITY OF NOT HITTING THE TARGET

There are three levels of accumulating, averaging, and ranking variables in the FRAGHAZ program. First we average for the trajectory integration end points in the same 100-ft Hazard Volume increment. Then we accumulate for each 100-ft increment, the contribution from each fragment in a single replication or treatment. Finally, we average or rank across all replications or treatments. Ranking is done in SORT routines so that we may specify minima, maxima, and percentile values for the appropriate variables. All final output variables except number of final impacts, and trajectories with range greater than the maximum calculation range, are based on the accumulations done here. The two mentioned variables are necessarily accumulated at the end of each trajectory. Common to density and probability of not hitting the target are two presented areas - total and target. Both presented areas are in the plane perpendicular to the trajectory.

The total presented area (TA) involves projecting the 100-ft range increment volume containing the current trajectory point into the plane perpendicular to the trajectory (Figure 15). The top of the increment is projected using SIN (LE). The mid-vertical panel, rather than the front vertical panel, is projected using COS (LE). The mid-panel is used to obtain a proper average. This can be seen qualitatively by considering the first increment (0 to 100 ft) of the pie-shaped Hazard Volume. Assuming a horizontal trajectory, the density would be infinite if the front vertical panel (area = 0) were used. Likewise, the density would be a maximum if the rear vertical panel were used. It is the mid-vertical panel which produces the average as the trajectory proceeds through the increment. The presented area of the increment (TA) is thus the sum of projected areas of the top and mid-vertical panels. It is the same for ascending and descending trajectories.

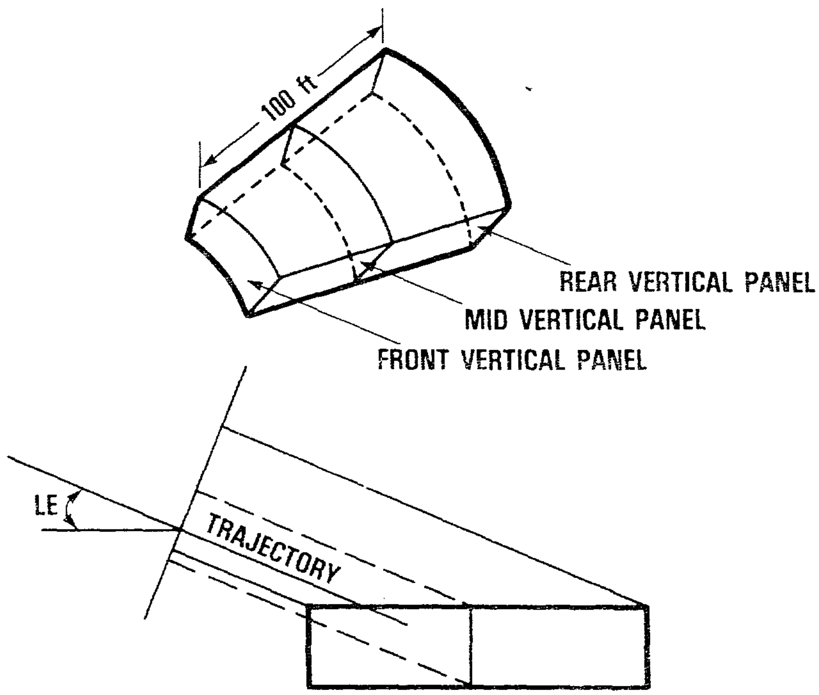


FIGURE 15. TOTAL PRESENTED AREA

The target presented area is shown in Figure 16. The target face (HM x WM) is always perpendicular to the plane of the trajectory. When the trajectory is descending, we project the top and front face, and the sum is the presented area of the target. When the trajectory is ascending, as after a ricochet, only the front of the target is projected. The top is masked by the front face and the bottom is in contact with the ground plane.

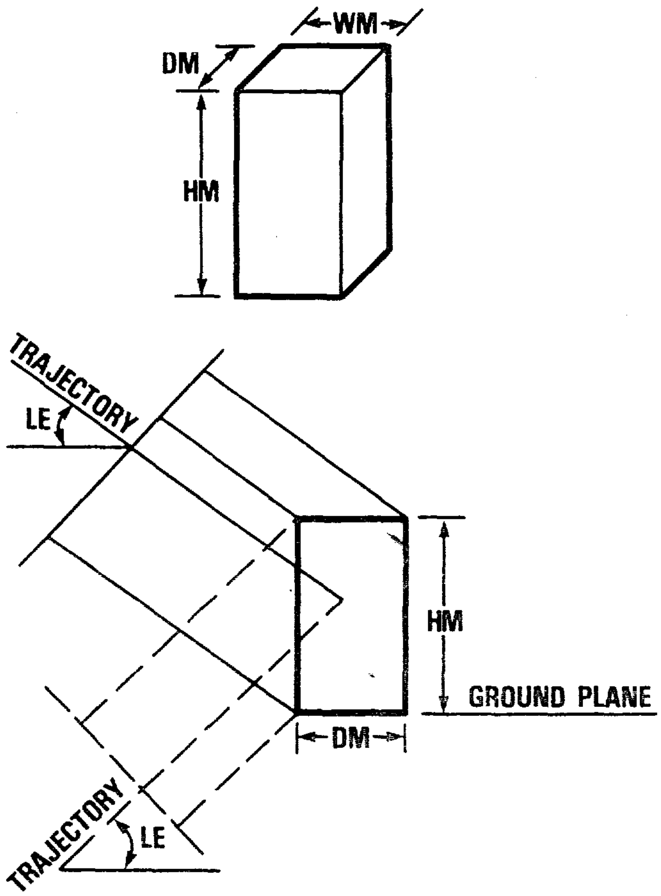


FIGURE 16. TARGET PRESENTED AREA

Probability of hit is based on the Poisson distribution which can be stated as follows:

$$P_x = \frac{\lambda^x}{x!} e^{-\lambda}$$

where

P_x = Probability of exactly x successes (hits)
e = Napierian base (2.718...)
λ = Expected number of successes (hits)

$$\lambda = \frac{NX \cdot \dot{M}A}{TA}$$

where

NX = number of fragments
MA = target presented area
TA = total presented area

The probability of exactly zero hits is:

$$P_o = e^{-\lambda}$$

Then the probability of one or more (at least one) hit is:

$$P_{>0} = 1 - P_o = 1 - e^{-\lambda}$$

To accumulate probability of hit for two or more trajectories, the equation is:

$$P_H = 1 - e^{-\lambda_1} \cdot e^{-\lambda_2} \cdot e^{-\lambda_3} \cdot \ldots\ldots \cdot e^{-\lambda_n}$$

From this equation it should be clear why we accumulate the probability of not hitting the target as a product.

<u>Line 584</u>

Here we calculate the number of fragments connected with the current trajectory. Y2 is the fragment multiplier explained in Appendix D. We have previously (line 244) multiplied the fragment multiplier by the angular width (AS) of the Hazard Volume. Here we need only multiply by the number of units that were specified in the input to obtain the number of fragments associated with the trajectory.

<u>Lines 585-586</u>

We increment the counter (P) in line 585. This keeps track of the number of integration increment end points in the 100-ft increment being considered. If the 100-ft increment designator (R) set in line 545 or 557 exceeds the maximum calculation range we do not make any hazard calculations.

<u>Lines 590-591</u>

Here we accumulate the total (hazardous and non-hazardous) average number of fragments for the 100-ft increment designated by (R). Note that we accumulate for the first trajectory end point (P = 1) only. The number of fragments is the same throughout the 100-ft increment.

<u>Lines 592-598</u>

Here we calculate the absolute value of the elevation angle. We then calculate the total presented area (TA) as described in Figure 15. The total presented area is the same for descending and ascending trajectories. We then calculate the target presented area (MA) as described in Figure 16. The vertical velocity (DI (4)) is positive for ascending trajectories and negative for descending trajectories.

Lines 599-601

Here we accumulate total (hazardous and non-hazardous fragments) density. Line 599 keeps a running average of the density at each integration end point with the counter (P). A running average is used so we will not have to go back and average after we leave the 100-ft increment being considered. Density at each point is NX/TA for the (N4) units specified. In line 600 we add the current running average to the accumulator (DT (R)). We divide the running average density by the number of replications or treatments (NR) to average over all replications or treatments. Since we are adding running averages, we must subtract the previous running average divided by (NR) using the variable (S1). The remaining variables are handled in essentially the same way.

Lines 602-604

Here we accumulate the probability of not hitting the target with the total (hazardous and non-hazardous) number of fragments. Note that here we multiply the running average of the probability of not hitting the target (XP) by the accumulator (PT (R)). As such, we must divide out the previous running average (S2).

Lines 605-606

Here we check to see if the fragments are hazardous by comparing the kinetic energy of the current fragment with the kinetic energy criterion. If the fragments are not hazardous we set the number of fragments associated with the trajectory to zero. This, in effect, averages in a zero for hazardous density and a one for hazardous probability of not hitting the target.

Lines 607-609

Here we accumulate the average number of hazardous fragments averaged over all replications or treatments. See lines 599-604 for discussion of (P) and (S) variables.

Lines 610-613

Here we accumulate hazard density. In line 611, the accumulator (DH (R)) is over all replications or treatments. In line 612 the accumulator (D6H (T, R)) is separate for each replication or treatment. This variable will be used to calculate minimum, maximum, and percentile values for hazardous density. See lines 599-604 for discussion of (P) and (S) variables.

Lines 614-619

Here we accumulate probability of not hitting the target. The running average (ZP) is for the number of units specified while (ZZP) is for a single unit. As such PH(R) is for the number of units specified while (PX (T, R)) is for a single unit. PX (T, R) will be used to calculate minimum, maximum, and percentile values for probability of hit. See lines 599-604 for discussion of (P) and (S) variables.

Line 620

The current 100-ft increment designator (R) is set equal to (RL). If the next integration increment end point should fall outside the current 100-ft increment, then this will be sensed in line 562 and all the applicable variables for this block will be initialized once more to make ready for the new 100-ft range increment.

Line 621

If the current altitude (DI (5)) of the fragment is greater than zero (ground level) then we go back to line 437 (2140) and start the next trajectory integration increment. If DI (5) is equal or less than zero then we have hit the ground and we pass to BLOCK-19 where we will consider ricochet.

BLOCK-19. CHECK FOR RICOCHET AND COMPUTE NEW INITIAL CONDITIONS FOR RICOCHETING FRAGMENT

Lines 627-628

Here we compute the current values of elevation angle and velocity. These are the incident values for possible ricochet.

Line 629

Here we terminate the trajectory if the number of ricochets is greater than six. This is necessary because under tail wind conditions and low fragment velocity, an endless loop can occur when the velocity lost in ricochet is made up by the tail wind.

Line 630

Here we test to see if the incident angle is greater than the critical angle and whether the velocity is less than 20 ft/s. In either case, the trajectory is terminated. Note that we use the absolute value of the elevation angle (E) in deg for the critical angle equation (see Appendix E).

Line 631

Again we use the absolute value of the elevation angle (E) in deg and give it the name (EY). All of the ricochet equations use a positive incident angle in deg.

Lines 632-643

The variables (VQ) are the ratios of ricochet velocity to incident velocity. The variables (EQ) are the ratios of ricochet angle to incident angle. All equations are a function of the incident angle (EY) only. Each set of six equations correspond to the six specific soil constants given in Appendix E. Figures 17 and 18 show these ratios graphically as a function of incident angle and soil constant.

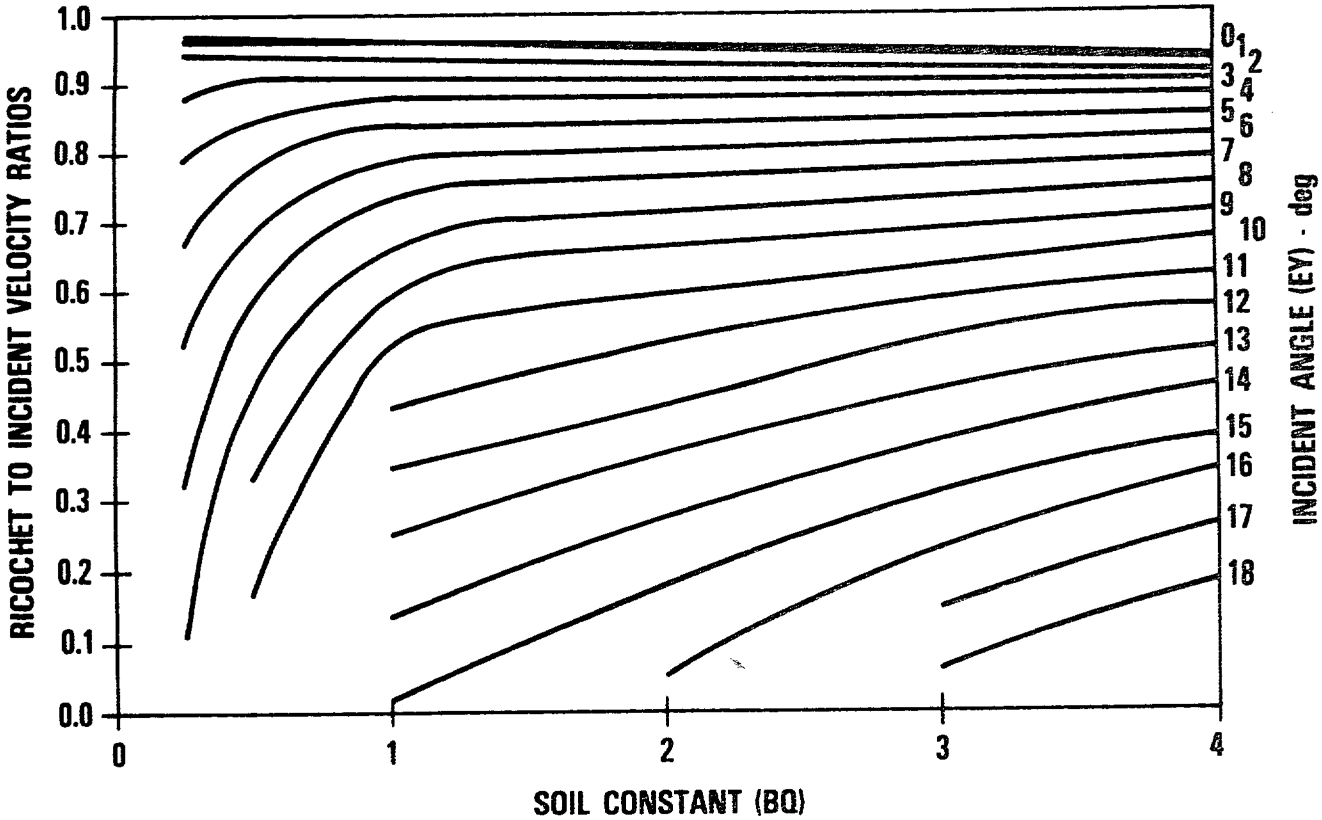


FIGURE 17. RICOCHET TO INCIDENT VELOCITY RATIOS

<u>Lines 644-661</u>

Since the soil constant is seldom exactly equal to one of the six specific soil constants in Appendix E, these lines are used to linearly interpolate between the velocity and angle ratios given above. The ratios are now labeled (QV) for velocity and (QE) for angle.

<u>Lines 662-664</u>

These are the velocity (VA) and elevation angle (EA) after ricochet. (XE) is computed in deg for a later call to the trajectory integration step subroutine (BLOCK-26).

<u>Lines 665-666</u>

The trajectory is terminated if the ricochet velocity is less than 20 ft/s. If not, we increment the rebound (ricochet) counter to keep track of the number of ricochets for the trajectory. Generally, the number of ricochets will not exceed four.

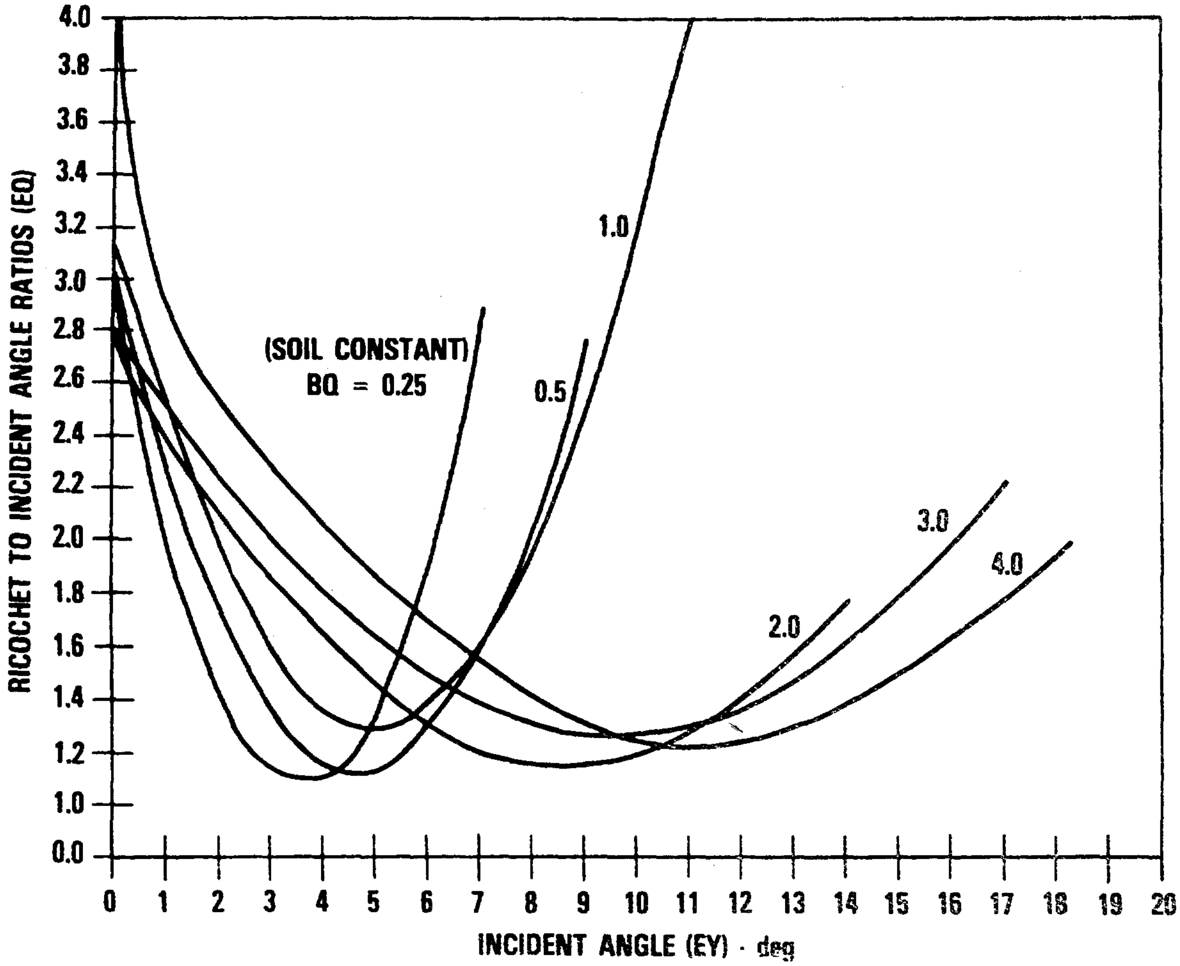


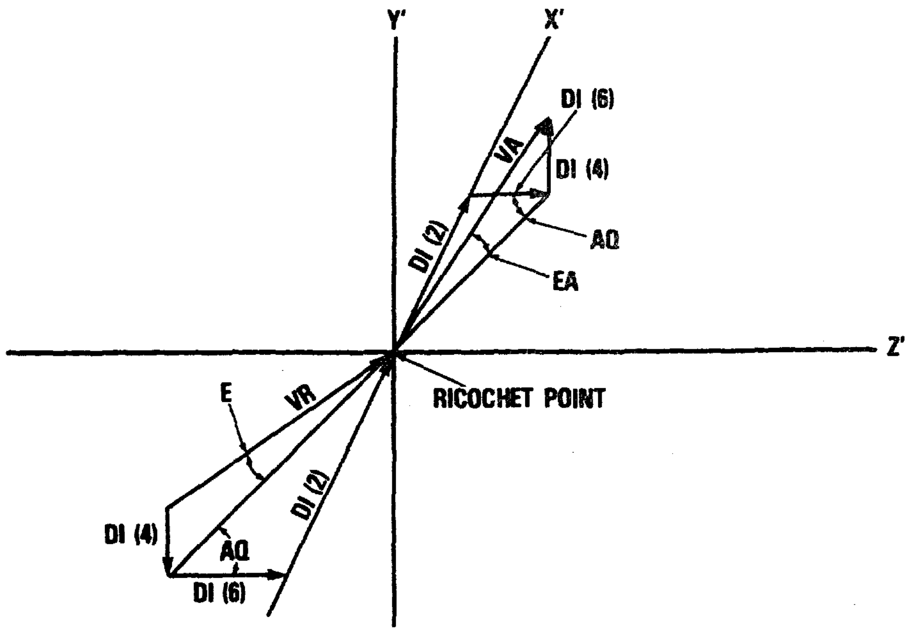
FIGURE 18. RICOCHET TO INCIDENT ANGLE RATIOS

<u>Lines 667-675</u>

A ricochet can be looked at as the start of a new trajectory where the component displacements and velocities must be specified. The component displacements (DI (3), DI (5), and DI (7)) are the same as before ricochet so nothing needs to be done to these variables. The component velocities (DI (2), DI (4), and DI (6)) are affected by ricochet and new values are calculated using the new elevation angle (EA) and the new velocity (VA). The ricochet trajectory is in the same vertical plane as the incident trajectory. Therefore, the angle (AQ) is the same before and after ricochet as shown in Figure 19. The test in line 668 is for the existence of a crosswind component. With a crosswind component we must calculate the angle (AQ) as shown in Figure 19 before calculating DI(2) and DI(6).

<u>Lines 676-679</u>

If the velocity is greater than 20 ft/s then we call the trajectory integration step subroutine just as if we were starting a new trajectory. The variable (CY) is set to zero for the check to see at what range the trajectory pierces the top of the Hazard Volume from below. This check is accomplished in BLOCK-17. Finally we go to 2140 (line 437) to start the next trajectory integration step. If the trajectory is terminated (no ricochet or velocity less than 20 ft/s) then we proceed to BLOCK-20.



BEFORE RICOCHET

AQ = ATAN (DI (2)/DI (6))

AFTER RICOCHET

VA IN SAME VERTICAL PLANE AS VR

AQ THE SAME AS BEFORE RICOCHET

DI (4) = VA * SIN (EA)

DI (2) = VA * COS (EA) * SIN (AQ)

DI (6) = VA * COS (EA) * COS (AQ)

FIGURE 19. COMPONENT VELOCITIES AFTER RICOCHET

BLOCK-20. COMPUTE AND PRINT INITIAL AND FINAL CONDITIONS FOR CURRENT FRAGMENT TRAJECTORY

<u>Lines 685-687</u>

Here we calculate distance (DN), crossrange (XR), and range (RN).

<u>Lines 688-692</u>

Here we accumulate the trajectories with range greater than the maximum calculation range declaration in the input. The variable (TJ) accumulates the trajectories for all replications or treatments. It is not an average.

Lines 693-694

(XN (R)) accumulates the number of final impacts in each 100-ft increment and averages over all replications or treatments. (YN (T, R,)) accumulates the number of final impacts for each 100-ft increment and each replication or treatment. These latter data will be sorted such that we can obtain the minimum and maximum number of final impacts for each 100-ft increment.

Lines 695-698

Here we calculate crossangle (XA), final impact velocity (VF) and final kinetic energy (CKE). If the final kinetic energy is above 9999.9, then we will print out 9999.9. This occurs when a high velocity fragment fails to ricochet close in.

Lines 699-702

If the conditions are met in line 699, then we print out the initial and final values for the current trajectory. (NP) is the number of replications or treatments for which we will print out the initial and final conditions for all the fragments. This value was selected in the input. It is usually wise to print out one or two replications or treatments, for these data serve as a spot check to assure us that the program is running in the manner intended. For example, if we were studying the effects of reducing the kinetic energy criterion from 58 ft-lbs to 10 ft-lbs using the MONTE CARLO option, we would want exactly the same trajectories for both. We would use the same random number seed for both and we could check to see if we were getting the same trajectories by examining the trajectory tables. Line 702, marked 3450, sends us back to line 358 to start the next trajectory. Explanations of the table headings for the initial and final trajectory conditions are given in Appendix H - TEST CASES.

Lines 703-706

Here, at the end of a replication or treatment, we accumulate the total (hazardous and nonhazardous fragments) average probability of hit and the average hazard probability of hit. These variables are averaged over all replications or treatments (NR). (PT (R)) and (PH (R)), the probabilities of not hitting the target for the number of units specified (N4), will be set back to one in lines 351 and 352 at the beginning of the next replication or treatment.

Lines 707-711

In line 707 we use a printer command to change back to standard character size to print the replication or treatment number, the soil constant, altitude, and wind speed for the next replication or treatment. If we had chosen the MONTE CARLO option, line 709 returns to line 297 (1160) for the next replication. If we had chosen the FULL FACTORIAL option, line 711 returns to line 320 (1169) for the next treatment.

BLOCK-21. SORT FOR MAXIMA, MINIMA AND PERCENTILES

At this point, all trajectories and replications or treatments have been completed. We are now ready to begin work on the output variables. First, it is necessary to sort three variables, each having two dimensions (T) and (R); that is, across all 100-ft increments for each replication or treatment. The three variables and their associated sub-blocks are:

Sub-Block	Variable	Description
21A	YN	Number of final impacts
21B	D6H	Hazardous density
21C	PX	Hazardous probability of not hitting the target

Sorting is required to obtain minimum, maximum, and percentile values for output variables.

BLOCK-21A. MAXIMUM AND MINIMUM NUMBER OF FINAL IMPACTS

Here we sort the number of final impacts from smallest to largest across the (NR) replications or treatments for each 100-ft increment of the Hazard Volume. Both hazardous and nonhazardous fragments are included.

Lines 718-722

The loop for (R) is begun here and minimum and maximum values are set if there is only one replication or treatment.

Lines 723-732

The main sort loop is executed here and minimum and maximum values for each 100-ft increment are established in lines 731 and 732.

BLOCK-21B. MAXIMUM, MINIMUM, AND PERCENTILE HAZARD DENSITY

Lines 738-743

The loop for (R) is begun here and minimum, maximum, and percentile values are established if there is only one replication or treatment.

Lines 745-752

The sort loop is executed here, rearranging the hazard densities in ascending order (minimum to maximum) for each 100-ft increment across replications or treatments.

<u>Lines 753-763</u>

The minimum and maximum hazard densities are calculated in lines 753 and 754 for each 100-ft increment. In lines 755 to 760 we calculate the element number in the sorted lists for each 100-ft increment corresponding to the 50th percentile (P5) and the percentile designated by the user in the input (P9). For example, if we had 60 replications or treatments, then the 50th percentile element would be the 30th up from the minimum. If we had specified a 90th percentile in the input, then the element (P9) would be the 54th up from the minimum in the sorted list. This element would have 6 elements (10%) above it which is consistent with the definition of a 90th percentile. Lines 757 and 758 round up to the next most hazardous element if P5 or P9 (lines 755 and 756) is not an integer. If P5 and P9 are less than one, then lines 759 and 760 define the element for both percentiles as the first or minimum value in the sorted list. Finally, in lines 761 and 762, both percentile hazard densities are calculated for each 100-ft range increment.

BLOCK-21C. SORT PROBABILITY OF NOT HITTING THE TARGET

<u>Lines 768-769</u>

The main loop for (R) begins here. When there is only one replication or treatment, we skip the sort loop entirely.

<u>Lines 770-777</u>

The main loop is executed here using the probability of not hitting the target with a single unit. The probabilities are sorted from smallest to largest. Note that the probabilities of hit (1-PX) are effectively sorted from largest to smallest. The minimum, maximum, and percentile values will be calculated in BLOCK-22 (lines 809 to 824).

BLOCK-22. COMPUTE AND PRINT OUTPUT DENSITY, P-HIT, AND NUMBER OF FINAL IMPACTS FOR GIVEN DISTANCE INCREMENT AND NUMBER OF UNITS

The final output consists of three tables for each of the 100, 200, 300 and 400-ft increments, a total of 12 tables (See Appendix H-TEST CASES). We shall refer to the three tables as Table 1, Table 2, and Table 3. Table 1 is printed out in BLOCK-22, Table 2 in BLOCK-23, and Table 3 in BLOCK-24. In this block, BLOCK-22, the output variables for BLOCKS 22 and 23 will be calculated. Outputs for density and probability of hit are weighted averages. Weighting is proportional to the size of each 100-ft increment as described in Appendix G.

Rather than describing each output variable, which is already done in the Glossary (Appendix C) it is considered more useful for the user to trace each output variable from start of accumulation to output. In Table 3 (Variable Traces), we identify each output variable for output Table 1, Table 2, and Table 3. The progress of a trace identifies the variable name and, in parenthesis, the line number where the calculation is made. Variables in each of the three output tables (see Appendix H) are addressed left to right.

TABLE 3. VARIABLE TRACES - ACCUMULATION TO OUTPUT

OUTPUT TABLE 1 (BLOCK-22) (FOR THE NUMBER OF UNITS SPECIFIED)

	Variable	Trace
1.	Average Total Number of Fragments	NT(R) (591) --TN(R) (794) -- TN(R) (842)
2.	Average Total Density	DT(R) (600) -- TD(R) (795) -- TD(R) (842)
3.	Average Total Probability of Hit	PT(R) (603) -- TP(R) (704) -- FTP (R) (796) -- FTP (R) (842)
4.	Average number of Hazardous Fragments	NH(R) (608) -- HN(R) (797) -- HN(R) (842)
5.	Average Hazard Density	DH(R) (611) -- HD(R) (798) -- HD(R) (842)
6.	Average Hazard Probability of Hit	PH(R) (616) -- HP(R) (705) -- FHP(R) (807) -- FHP(R) (842)
7.	Minimum number of Final Impacts	YN(T, R) (694) -- YN(J, R) (727) -- N8MIN(R) (731) -- T8MIN(R) (826) -- T8MIN(R) (842)
8.	Average Number of Final Impacts	XN(R) (693) -- TI(R) (825) -- TI(R) (843)
9.	Maximum Number of Final Impacts	YN(T, R) (694) -- YN(J, R) (727) -- N9MAX(R) (732) -- T9MAX(R) (827) -- T9MAX(R) (843)
10.	Number of Trajectories with Range Greater than MRA	TJ (691) -- TJ (845)

OUTPUT TABLE 2 (BLOCK-23) (FOR THE NUMBER OF UNITS SPECIFIED)

	Variable	Trace
11.	Maximum Hazard Density	D6H(T, R) (612) -- D6H(J, R)((749) -- D8MAX(R) (741, 754) -- X8DMAX(R) (804) -- X8DMAX(R) (859)
12.	Percentile Hazard Density	D6H(T, R) (612) -- D6H(J, R) (749) -- D9(R) (743, 762) -- X9D(R) (806) -- X9D(R) (859)
13.	50th Percentile Hazard Density	D6H(T, R) (612) -- D6H(J, R) (749) -- D5(R) (742, 761) -- X5D(R) (805) -- X5D(R) (859)
14.	Minimum Hazard Density	D6H(T, R) (612) -- D6H(J, R) (749) -- D7MIN(R) (740, 753) -- X7DMIN(R) (803) -- X7DMIN(R) (859)
15.	Maximum Hazard Probability of Hit	PX(T, R) (618) -- PX(J, R) (774) -- X8PMAX(R) (810) -- X8PMAX(R) (859)
16.	Percentile Hazard Probability of Hit	PX(T, R) (618) -- PX(J, R) (774) -- X9P(R) (824) -- X9P(R) (860)
17.	50th Percentile Hazard Probability of Hit	PX(T, R) (618) -- PX(J, R) (774) -- X5P(R) (823) -- X5P(R) (860)
18.	Minimum Hazard Probability of Hit	PX(T, R) (618) -- PX(J, R) (774) -- X7PMIN(R) (809) -- X7PMIN(R) (860)

TABLE 3. VARIABLE TRACES - ACCUMULATION TO OUTPUT (CONTINUED)

OUTPUT TABLE 3 (BLOCK-24) NUMBER OF UNITS TO JUST EXCEED HAZARD DENSITY CRITERION (DC)

Variable	Trace
19. Minimum Number of Units	D6H(T, R) (612) -- D6H(J, R) (749) -- D8MAX(R) (741, 754) -- X8DMAX(R) (804) -- Y7DMIN(R) (873, 875) -- Y7DMIN(R) (944)
20. Percentile Number of Units	D6H(T, R) (612) -- D6H(J, R) (749) -- D9(R) (743, 762) -- X9D(R) (806) -- Y9D(R) (878,880) -- Y9D(R) (944)
21. 50th Percentile Number of Units	D6H(T, R) (612) -- D6H(J, R) (749) -- D5(R) (742, 761) -- X5D(R) (805) -- Y5D(R) (883, 885) -- Y5D(R) (944)
22. Maximum Number of Units	D6H(T, R) (612) -- D6H(J, R) (749) -- D7MIN(R) (740, 753) -- X7DMIN(R) (803) -- Y8DMAX(R) (888, 890) -- Y8DMAX(R) (944)

NUMBER OF UNITS TO JUST EXCEED HAZARD PROBABILITY OF HIT CRITERION (PC)

Variable	Trace
23. Minimum Number of Units	PX(T, R) (618) -- PX(J, R) (774) -- Z8PMAX(R) (903) -- NP2(1, R) (908, 910, 912) -- NP2(1, R) (944)
24. Percentile Number of Units	PX(T, R) (618) -- PX(J, R) (774) -- Z9P(R) (904) -- NP2(2, R) (916, 918, 920) -- NP2(2, R) (945)
25. 50th Percentile Number of Units	PX(T, R) (618) -- PX(J, R) (774) -- Z5P(R) (901) -- NP2(3, R) (924, 926, 928) -- NP2(3, R) (945)
26. Maximum Number of Units	PX(T, R) (618) -- PX(J, R) (774) -- Z7PMIN(R) (902) -- NP2(4, R) (932, 934, 936) -- NP2(4, R) (945)

Notes:

Total - Includes hazardous and nonhazardous fragments
Hazard - Includes hazardous fragments only
MRA - Maximum Calculation Range

Generally, the array variables in Table 3 (Variable Traces) are identified by one or two code characters in the variable name. Identification is as follows:

Character	Variable Identification
N	Number of fragments, sometimes a T is used
T	Usually identifies a variable including Total (hazardous and nonhazardous) fragments
H	Identifies variables with hazardous fragments only
D	A fragment density variable
P	A probability of hit or not-hit variable
5	A 50th percentile value
7	A minimum value for density or probability of hit
8	A maximum value for density or probability of hit
9	A value for the percentile specified in the input
(H, T)	A variable without an H and T will usually contain hazardous fragments only

Line 787

This starts the output table loop. The loop runs from here to line 961 and covers BLOCKS-22, 23, and 24. The first full loop will print out Tables 1, 2, and 3 for 100-ft increments of the Hazard Volume. The appropriate variables are zeroed in lines 952-958, and then the next pass begins for printing out Tables 1, 2, and 3 for 200-ft increments of the Hazard Volume. This continues until Tables 1, 2, and 3 are printed out for 400-ft increments of the Hazard Volume.

If the user wants only the basic 100-ft increment data, then he should change 400 to 100 in line 787.

Lines 789-793

These lines control the variables for computing running or cumulative weighted averages. These averages apply only to density and probability of hit. See Appendix G for details on weighting factors.

Lines 794, 797, 825, 826, 827

These lines apply to number of fragments and number of final impacts as a function of range (R) and require no weighting factors; they are accumulated by simple addition.

Lines 795-796, 798-810

These lines compute running or cumulative weighted averages for density and probability of hit. An example may help to clarify the procedures. Suppose we were calculating a 300-ft increment from three 100-ft increments, 1200-1300, 1300-1400, and 1400-1500. Weighting factors we call (KW - See Appendix G) and the cumulative sum of the weighting factors we call (SUM). The running weighted average we will call (RWAVG). Given the following table for density or probability of hit.

Range	Density or PH (DPH)	KW	SUM	RWAVG
1200-1300	0.6	12.5	12.5	0.6
1300-1400	0.3	13.5	26.0	0.444
1400-1500	0.2	14.5	40.5	0.357

The basic formula is:

$$RWAVG = (RWAVG * (SUM - KW) + DPH * (KW))/SUM$$

On the first pass through the loop we would have

$$RWAVG = ((RWAVG)(12.5 - 12.5) + 0.6\,(12.5))/12.5 = 0.6$$

Note that at the beginning of every averaging sequence, the term (SUM-KW) is always zero since SUM and KW always start out with the same value. This effectively initializes RWAVG to zero regardless of its value from the previous sequence. SUM is zeroed in line 829.

If we were interested in only 100-ft increments we would stop here and proceed to the next 100-ft increment. Going on, the second pass produces:

$$RWAVG = (0.6\,(26.0 - 13.5) + 0.3\,(13.5))/26.0 = 0.444$$

If we were dealing with 200-ft increments we would stop here and proceed to the next 200-ft increment. Going on, the third pass produces:

$$RWAVG = (0.444\,(40.5 - 14.5) + 0.2\,(14.5))/40.5 = 0.357$$

If we were dealing with 300-ft increments, as we are in the example, we would stop here and proceed to the next 300-ft increment.

Lines 818-824

Here we designate elements in the sorted lists for the 50th percentile and the percentile specified in the input. Since we are dealing with the sorted lists of probability of not hitting the target, the procedure is somewhat different from what it was for density in lines 755-762. What we ultimately want for calculating number of units required to just exceed the probability of hit criterion (PC), is the probability of hit for a single unit or interaction area. For example, if we wanted the 90th percentile value and we had only 10 replications, the element selected would be 2 from line 819. This would be the second element counted up from the minimum in the sorted (minimum to maximum) list of probabilities of not hitting the target. Since P(Hit) = 1 - P(NotHit), this element corresponds to the 9th element up from the minimum of the effectively sorted list of probabilities of hitting the target with a single unit. Line 818 designates the element for the 50th percentile. Lines 820-822 calculate the values of P5 and P9 for special cases. Finally, lines 823 and 824 calculate the 50th and specified percentiles for probability of hitting the target with a single unit for each 100-ft increment of range. Note that P5 and P9 are the same variables used for density (lines 755-762) since there is no conflict between the two routines. As before, if the element calculated is not an integer we always move to the more hazardous element in the sorted list using the equations in lines 820 and 821.

Lines 833-846

These lines print out Table 1 for 100, 200, 300, and 400 ft increments in four repeated passes of the overall loop. See Appendix H for examples of output Tables 1, 2, and 3.

BLOCK-23. PRINT HAZARD DENSITY AND PROBABILITY OF HIT FOR NUMBER OF UNITS SELECTED

Lines 852-861

All values for this printout have already been calculated in BLOCK-22. Like Table 1 in BLOCK-22, Table 2 here reflects the number of units selected in the input (N4).

BLOCK-24. COMPUTE AND PRINT NUMBER OF UNITS REQUIRED TO JUST EXCEED HAZARD DENSITY AND P-HIT CRITERIA

Lines 871-894

Here we calculate the minimum, specified percentile, 50th percentile and maximum number of units required to just exceed the density criterion (DC). We use the densities previously calculated for the number of interaction areas or units (N4) selected in the input. This is a linear calculation and amounts to:

$$No.\ of\ Units\ Required = \frac{(DC)\,(N4)}{Density_{N4}} + 0.01$$

Lines 895-905

Here we first compute 50th percentile, minimum, maximum and specified percentile running or cumulative weighted averages for the probability of hit with a single unit in lines 901-904. Then we make use of the following equation:

$$PC = 1-(1-PH_1)^{NP} + 0.01$$

where

PC = Probability of hit criterion.
PH_1 = Probability of hit for a single unit.
NP = Number of units required.

Then

$$NP = \frac{ln\ (1-PC)}{ln\,(1-PH_1)} + 0.01$$

where 0.01 is added to made sure we just exceed the probability of hit criterion and never get a zero.

Note that we print out four values of density and four values for probability of hit: minimum, specified percentile, 50th percentile, and maximum. The values in this table, Table 3, correlate with the values in Table 2. Any row and column element in Table 3 can be computed from the column directly above in Table 2 and using the same row element. For density use the equation above for lines 871-894. This correlation should be exact. For probability of hit, the calculation will only be an approximation. From Table 2 we must first calculate the probability of hit for a single unit:

$$PH_{N4} = 1-(1-PH_1)^{N4}$$

where

PH_{N4} = Probability of hit for the selected number of units in Table 2.
PH_1 = Probability of hit for a single unit.
N4 = Number of units selected in the input upon which Table 2 is based.

Solving for PH_1 we have

$$PH_1 = 1-e^{\frac{ln\,(1-PH_{N4})}{N4}}$$

Then from above

$$NP = \frac{ln\,(1-PC)}{ln\,(1-PH_1)} + 0.01 = \frac{ln\,(1-PC)\,(N4)}{ln\,(1-PH_{N4})} + 0.01$$

This approximation will be fairly accurate when the number of units required is less than 10. As the number of units required increases the accuracy will drop off where the error could be more then five percent. The problem involves raising fractions to larger powers where significant digits are lost in single precision arithmetic.

Late in the preparation of this report, it was decided to replace average values with 50th percentile values in output Tables 2 and 3 as the measures of central tendency. This provides a better method of presenting the distribution of hazard values within which the specified percentile (currently the 90th percentile) can be evaluated. In some cases, particularly at the far ranges, 90th percentiles can be less hazardous than the arithmetic average values. Average hazard density and hazard probability of hit, however, are maintained in output Table 1. It is planned to incorporate the average number of units required to just exceed the hazard density and hazard probability of hit criteria in Table 1. In the meantime, the user may calculate these values by using the equations above in this block along with the average hazard values in Table 1.

<u>Lines 941-951</u>

Table 3 is printed out here. Referring to Appendix H, it can be seen that Table 3 correlates with Table 2; that is, maximum density or probability of hit produces a minimum number of units required to just exceed the density and probability of hit criteria. These are the most hazardous conditions.

<u>Lines 952-958</u>

All appropriate accumulating variables are zeroed before beginning the next combined range increment.

<u>Lines 959-961</u>

Here we write out the density and probability of hit criteria at the end of Table 3 and then set maximum range to hundreds of feet. Then we loop and begin the next combined range increment.

<u>Lines 962-964</u>

Here we set the printer to normal character mode and then close the printer port before ending the program.

BLOCK-25. FUNCTION SUBPROGRAM TO CALCULATE RANDOM NUMBERS

This is the portable random number generator which generates uniform random numbers between zero and one. Appendix F discusses the generator and provides a test for portability. If the user cannot meet the test in Appendix F then he will have to use hand cases to check the MONTE CARLO option. In any event, the user is free to use any random number generator he chooses.

All the variables in BLOCK-25 are double precision except (RND). The single precision variable (RND) is returned to the main program at the point of call. As seen in lines 984 and 985 (RND) has six significant digits to be compatible with the word size on microcomputers. As a result, (RND) can be equal to zero. If this occurs then line 985 causes the program to go through another cycle to produce a random number (RND) not equal to zero. A random number equal to zero will stop the program at line 400 where we take the natural log of the random number.

The random number generator is called from eight places in the MONTE CARLO option.

Random Variable	Call Line
Soil Constant (BQ)	332
Altitude (ALT)	333
Wind Speed (WS)	334
Height of Origin (HO)	364
Elevation Angle (E)	365
Initial Velocity (V)	400, 401
Drag Coefficient (D1)	417

Note that the random number generator is called by RND(UDUM) where UDUM is always equal to zero. This isolates the seed and reseed variable (UIX) from the main program. UIX is properly manipulated by lines 972 and 983.

BLOCK-26. SUBROUTINE FOR SELECTING INTEGRATION STEP

The integration step is a function of the elevation angle at the start of the trajectory and after each ricochet. Since the elevation angle (XE) after ricochet will always be positive, lines 994-997 will only apply to the start of the trajectory where the elevation angle (XE) can be negative.

The integration step is shown graphically in Figure 20. The integration step for negative elevation angles at the start of the trajectory may be as much as 50 ft or a very small value depending on the value of (HO) and the elevation angle (XE) specified in lines 994-997.

A constant displacement integration step is used in lieu of a constant time step to decrease the running time of the program. For far-field trajectories where the time of flight is about 10s, use of a customary 0.01s time step would result in about 1000 passes through the Runge-Kutta routine. Using a displacement step, we would only need about 100 passes through the Runge-Kutta routine, reducing the running time by a factor of about 10.

The integration steps shown in Figure 20 were derived empirically; that is, by trial and error with thousands of trajectories. In all cases, running time was sacrificed to stability of the Runge-Kutta routine. Instability occurs at high elevation angles where the Runge-Kutta routine must negotiate tight turns at the top of the trajectory. The calculation of special time steps in BLOCK-12, line 460, also help to prevent instability. To a lesser extent, running time was sacrificed to accuracy. Range accuracy will seldom exceed two feet and most of the time the error will be less than one foot.

This subprogram is called from lines 395 at the beginning of each trajectory and from line 677 after each ricochet.

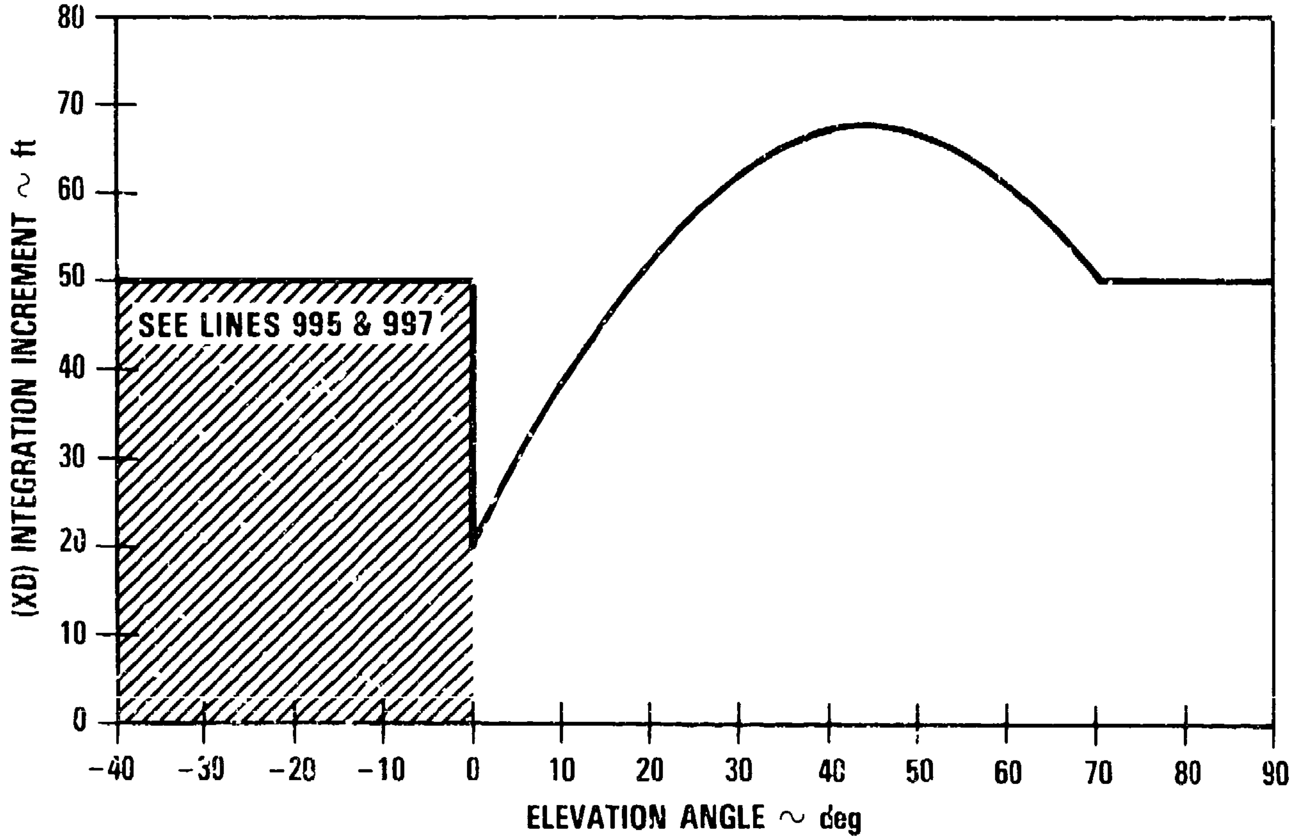


FIGURE 20. TRAJECTORY INTEGRATION INCREMENT

ADDITIONAL PROGRAM CONSIDERATIONS

PROGRAM TEST CASES

Test cases for the MONTE CARLO and FULL FACTORIAL options are contained in Appendix H. The details for the two tests are contained there.

WEAPON FRAGMENTATION DATA

Complete fragmentation data for 155mm projectiles (M107) and Mk82 Low Drag Bombs are contained in Appendix I. Details of these data are discussed there.

FUTURE IMPROVEMENTS

Drag Coefficients

The correlation for drag coefficients shown in Figure 11 is in need of improvement. Taking an area ratio of about 1.5 in Figure 11, the difference between the upper and lower limits is about 0.6. The overall range for drag coefficients is about 1.0; that is, between about 0.5 and 1.5. The range of uncertainty at an area ratio of 1.5 is then about 60 percent of the total range. This then represents an average reduction in uncertainty of about 40 percent. If we are to reduce the range uncertainty for far-field fragments to about plus or minus 10 percent, the uncertainty in drag coefficient will have to be reduced by about 75 percent. Work should continue in an effort to meet this goal. In addition, work should be done to better describe the shape of the transonic and supersonic portions of the drag curve.

Ricochet

An effort should be made to define fragment breakup characteristics at ricochet. The author knows of no such data. Figures 5 and 6 show predicted versus actual fragment recovery for 155mm projectiles and Mk82 Low Drag Bombs. The data in Figure 5 show excellent agreement. Figure 6, however, shows a discrepancy at ranges above 1800 ft. Predicted ranges go to about 3200 ft while actual recovery stops at about 2200 ft. The predicted long-range fragments are large and had they broken up would have gone to lesser ranges. With breakup, the predicted versus actual data might have been better at ranges above 1800 ft.

The fragment ricochet data used in the FRAGHAZ program were obtained from tests where the impact velocities ranged from 1000 to 5000 ft/s. In the FRAGHAZ program we consider impact velocities from 20 to 10,000 ft/s. Additional tests are required to check ricochet characteristics over this extended range of impact velocities.

Crosswind

As yet, no practical problems have been run with a crosswind. If it does become necessary to run crosswind problems, the program will have to be modified to account for the overlapping of fragments. Azimuth sectors larger than 10 deg may have to be considered and this would require changes to the methods we use to accumulate numbers of fragments, density, and probability of hit as a function of range.

FULL FACTORIAL Factor Levels

Currently, factor levels are chosen to cover 80 percent of the range of uncertainty for the random variables. For example, if the range of uncertainty for a uniform random variable was 10 to 20, then we would choose 11 and 19 as factor levels spanning 80 percent of the total uncertainty. For a normally distributed variable we would use $\pm 1.28\,\sigma$ which covers about 80 percent of the uncertainty for a normal variable. Changing factor levels can have a much greater effect on results than changing seeds in the MONTE CARLO option. Work is required to obtain a better basis for selecting factor levels.

APPENDIX A

HAZARD CURVE FITTING PROGRAM

Listing A-1 contains the program currently used to fit an equation to the retained points in the hazard tables. It is coded in Microsoft FORTRAN 77. The program uses a least squares fit by means of matrix inversion. The fitted equation is:

$$R = A_1 + A_2 \ell n N + A_3 \ell n^2 N$$

where
R = Hazard Range in Feet
N = Number of Units Required to Just Exceed the Hazard Criterion

The equation is very stable and does not exhibit oscillations between points as second order polynominals tend to do when only a few points are used.

The program does not include any statistical tests. The user may add any that seem appropriate.

Table A-1 is a sample of the program output using the hazard data of Table 2 in the GENERAL PROGRAM DESCRIPTION Section of this report. The user may want to start with the largest fractional number of units so as not to unduly bias the number of units less than one. It is probably best to run with all the fractional numbers also and pick the fit which best serves the purpose of the user. The fitted equation with all fractional retained points is plotted in Figure 7 of the GENERAL PROGRAM DESCRIPTION Section. Table A-1 shows that errors greater than 200 ft can be expected using the fitted equation. This is not unusual considering the erratic nature of hazardous fragment distributions in the hazard volume. The erratic nature is shown by the upper boundary defined by the solid lines connecting the retained points in Figure 7.

Generally only one decimal place is required for the constants of the fitted equation. If the absolute value of a constant is less than 10, the user may want to use two decimal places to retain accuracy.

The fitted equation represents a mean such that some retained points will lie above it and some below it. From a safety standpoint it may be desirable to have a curve which lies at or above all retained points. One way of doing this is to use a three point regression. Since the fitted equation has three constants, if only three points are used in the regression the resulting curve will go through the 3 points exactly. The three points could be selected as follows: (1) a minimum point at or near the minimum number of units required N, (2) a maximum point at or near the maximum N, (3) an intermediate point near the apparent knee of the curve. The procedure may have to be repeated to insure that the curve lies above all retained points but not unduly so.

LISTING A-1. FRAGFIT COMPILER LISTING

```
                                                              Page    1
                                                              01-07-87
                                                              14:35:37
D Line# 1      7                        Microsoft FORTRAN77 V3.31 August 1985

     C   PROGRAM FRAGFIT
     C   SECOND ORDER NATURAL LOG FIT

           REAL S,N(100),RN(100),T(3),X(3,3),YM(3),A(3),RE(100)
           INTEGER NP,P,R,C,I

           WRITE(*,'(A\)')' ENTER NUMBER OF POINTS (AT LEAST 3):
           READ(*,*)NP
           DO 10 P=1,NP
1          WRITE(*,*)' '
1          WRITE(*,'(A,I5)')' POINT NO.: ',P
1          WRITE(*,'(A\)')' ENTER NUMBER OF UNITS:
1          READ(*,*)N(P)
1          WRITE(*,'(A\)')' ENTER RANGE (FEET):
1          READ(*,*)RN(P)
1       10 CONTINUE
           DO 20 P=1,NP
1          T(1)=1.
1          T(2)=LOG(N(P))
1          T(3)=LOG(N(P))**2
1          DO 20 R=1,3
2          YM(R)=YM(R) + RN(P) * T(R)
2          DO 20 C=1,3
3          X(R,C)=X(R,C)+T(C)*T(R)
3       20 CONTINUE
           DO 30 R=1,2
1          DO 30 C=R+1,3
2          X(C,R)=X(R,C)
2       30 CONTINUE
           DO 40 R=1,3
1          DO 50 C=1,3
2          IF(C.EQ.R)GOTO 50
2          X(R,C)=X(R,C)/X(R,R)
2       50 CONTINUE
1          X(R,R)=1/X(R,R)
1          DO 60 I=1,3
2          IF(I.EQ.R)GOTO 60
2          DO 70 C=1,3
3          IF(C.EQ.R)GOTO 70
3          X(I,C)=X(I,C)-X(R,C)*X(I,R)
3       70 CONTINUE
2       60 CONTINUE
1          DO 80 I=1,3
2          IF(I.EQ.R)GOTO 80
2          X(I,R)=-X(I,R)*X(R,R)
2       80 CONTINUE
1       40 CONTINUE

           S=0
           DO 90 C=1,3
1          DO 100 R=1,3
2          S=S+(X(C,R)*YM(R))
2      100 CONTINUE
1          A(C)=S
1          S=0
```

LISTING A-1. FRAGFIT COMPILER LISTING (CONTINUED)

```
                                                                  Page    2
                                                                  01-07-87
                                                                  14:35:37
D Line# 1      7                        Microsoft FORTRAN77 V3.31 August 1985
1           90 CONTINUE

               OPEN(1,FILE='LPT1')
               WRITE(1,'(A)')' PROGRAM FRAGFIT'
               WRITE(1,'(/A)')' CONSTANTS'
               DO 110 I=1,3
1              WRITE(1,'(A,I1,A,F8.3)')' A',I,' =',A(I)
1          110 CONTINUE
               WRITE(1,'(/A)')' REGRESSION EQUATION : R = A1 + A2 * LN(N) + A3 *
              $(LN(N)) ** 2'
               WRITE(1,'(/14X,A)')'INPUT AND ERROR TABLE'
               WRITE(1,'(12X,A,6X,A,5X,A)')'INPUT','RANGE','RANGE'
               WRITE(1,'(5X,A,2X,A,3X,A,5X,A)')'INPUT','RANGE','ESTIMATE','ERROR'
               WRITE(1,'(4X,A,3X,A,7X,A,6X,A)')'NUMBER','FEET','FEET','FEET'
               DO 120 P=1,NP
1              RE(P)=A(1)+A(2)
1              RE(P) = A(1) + A(2)*LOG(N(P)) + A(3)*(LOG(N(P)))**2
1              WRITE(1,'(1X,F9.2,3X,I4,5X,F6.1,3X,F7.1)')N(P),INT(RN(P)),RE(P),RE
1             $(P)-RN(P)
1          120 CONTINUE
               CLOSE(1)
               END

Name      Type          Offset P Class

A         REAL            1276
C         INTEGER*4       1308
I         INTEGER*4       1312
INT                              INTRINSIC
LOG                              INTRINSIC
N         REAL              76
NP        INTEGER*4       1288
P         INTEGER*4       1292
R         INTEGER*4       1304
RE        REAL             876
RN        REAL             476
S         REAL            1316
T         REAL              16
X         REAL              28
YM        REAL              64


Name      Type            Size   Class

MAIN                             PROGRAM


  Pass One      No Errors Detected
                78 Source Lines
```

PROGRAM FRAGFIT

CONSTANTS
A1 = 264.379
A2 = 126.526
A3 = 36.365

REGRESSION EQUATION: R = A1 + A2 * LN(N) + A3 * (LN(N)) ** 2

TABLE A-1. INPUT AND ERROR TABLE

Input Number	Range Data		
	Input Range Feet	Range Estimate Feet	Range Error Feet
.12	50	159.6	109.6
.24	150	157.9	7.9
.43	250	183.5	-66.5
.62	350	212.2	-137.8
2.31	450	395.8	-54.2
5.16	550	569.9	19.9
8.14	650	689.6	39.6
12.72	750	821.4	71.4
20.41	950	976.8	26.8
34.63	1050	1169.8	119.8
53.12	1150	1340.9	190.9
67.73	1550	1444.0	-106.0
84.73	1750	1542.8	-207.2
150.71	1850	1813.7	-36.3
214.91	2050	1992.6	-57.4
335.26	2150	2229.7	79.7

APPENDIX B

FRAGHAZ COMPILER LISTING

Listing B-1 is the compiler code for the FRAGHAZ program. The program is divided into 26 BLOCKS and each line is numbered. An explanation of the code is given in the DETAILED PROGRAM DESCRIPTION section of the main body.

```
                                                              Page    1
                                                              11-21-87
                                                              09:03:08
D Line# 1      7                      Microsoft FORTRAN77 V3.31 August 1985
$LARGE
$DEBUG
C         F R A G H A Z
C         Quantity - Distance Program
C           (Fragmenting Munitions)


C   BLOCK 1
C   Declare Data Types for Variables, Dimension Arrays

      REAL ALT,ALTMAX,ALTMIN,AQ,AX,AY,AZ
      REAL B,BB,BQ
      REAL CD,CH,CKE,CL
      REAL D1,D2,D3,D4,DC,DD,DF,DLT,DM,DN,DR,DW,DX
      REAL E,EA,EC,EE,ES,EY
      REAL FG
      REAL G,GX
      REAL HM,HO,HS,HX
      REAL K1,K3,K4,K5,K9,KE,KK,KM,KW
      REAL LE
      REAL M1,M2,M3,MA,MN,MRA
      REAL N1,N2,NR,NX
      REAL P,PA,PC,PCTD,PI,PW,P5,P9
      REAL QE,QV
      REAL RN,RO
      REAL S1,S2,S3,S4,S5,S6,SCMIN,SCMAX,SIGS,SUM
      REAL T5,TA
      REAL V,VA,VF,VP,VR,VS,VXP,VYP,VZP
      REAL WD,WM,WS,WSMAX,WSMIN
      REAL XA,XD,XE,XP,XR,XV
      REAL Y,YE
      REAL ZP,ZZP
      REAL AE(500),AM(500),AR2(500)
      REAL D6H(100,97),D7MIN(97),D8MAX(97),D9(97),DI(7),DH(97),DO(7)
      REAL DT(97),DS(7),D5(97)
      REAL EQ(6)
      REAL FHP(97),FL(10,25),FTP(97),FW(500)
      REAL HD(97),HN(97),HP(97)
      REAL IE(500),IV(500)
      REAL N8MIN(97),N9MAX(97),NH(97),NP2(4,97),NT(97)
      REAL PH(97),PT(97),PX(100,97)
      REAL T8MIN(97),T9MAX(97),TD(97),TI(97),TN(97),TP(97)
      REAL VQ(6)
      REAL X7DMIN(97),X8DMAX(97),X5D(97),X9D(97),XK(4,7),XN(97)
      REAL X7PMIN(97),X8PMAX(97),X9P(97),X5P(97)
      REAL Y7DMIN(97),Y8DMAX(97),Y9D(97),Y2(36),YN(100,97)
      REAL Y5D(97),Z7PMIN(97),Z8PMAX(97),Z5P(97),Z9P(97)

      INTEGER AS
      INTEGER CX,CY
      INTEGER EZ
      INTEGER F1,F2,F3,F4,F5,F6,F7,F
      INTEGER I
      INTEGER J
      INTEGER K
      INTEGER MR
```

```
                                                               Page    2
                                                               11-21-87
                                                               09:03:08
D Line# 1      7                        Microsoft FORTRAN77 V3.31 August 1985
            INTEGER N4,NF,NP
            INTEGER PCT
            INTEGER R,RB,RI,RI2,RL,RZ
            INTEGER T,TJ
            INTEGER X5,XL
            INTEGER NL(10)

            DOUBLE PRECISION USE,UDUM

            CHARACTER Q*14,TS*64,H9(10)*19,NAM*14

      C  Assign Constant Values

            DATA M1/0.75/,M2/1.5/,M3/2.5/,VS/1116.4/
            DATA K1/286000./,K3/0.038239/,K4/33900./,K5/144./
            DATA G/32.174/,K9/450436./,PI/3.141593/
            DATA B/57.29578/,DR/0.0174533/,BB/6.283185/

      C  Assign Variable Constants

            DATA ES/10./,AS/10/
            DATA HM/5.72/,WM/1./
            DATA DM/0.55/
            PW=10000.*PI*AS/360.

      C  BLOCK 2
      C  Variables to be input at runtime
      C  Select Monte Carlo or Full Factorial Option

            WRITE(*,30)' Enter input (frag data) filename: '
         30 FORMAT(A\)
            READ(*,40)Q
         40 FORMAT(A)
            WRITE(*,30)' Enter output filename (Printer=LPT1): '
            READ(*,40)NAM
            WRITE(*,30)' Enter target description: '
            READ(*,40)TS
            WRITE(*,30)' Enter minimum soil constant (0.5 to 4.0): '
            READ(*,*)SCMIN
            WRITE(*,30)' Enter maximum soil constant (SCMIN to 4.0): '
            READ(*,*)SCMAX
            WRITE(*,30)' Enter height of ammo stack (feet): '
            READ(*,*)HS
            WRITE(*,30)' Enter stack inert ground standoff (feet): '
            READ(*,*)SIGS
            WRITE(*,30)' Enter number of units or interaction areas: '
            READ(*,*)N4
            WRITE(*,30)' Enter number of fragment multipliers: '
            READ(*,*)X5
            WRITE(*,30)' Enter number of fragments (500 MAX): '
            READ(*,*)NF
            WRITE(*,30)' Enter percentile (integer 1 to 99): '
            READ(*,*)PCT
            PCTD=FLOAT(PCT)/100.
        340 WRITE(*,30)' Select Option: Monte-Carlo (enter 1) - Full Factorial
           $ (enter 0): '
```

```
      READ(*,*)RZ
      IF(RZ.EQ.0) GOTO 350
      WRITE(*,30)' Enter number of replications (100 max): '
      READ(*,*)NR
  350 WRITE(*,30)' Enter number of replications / treatments to be print
     $ed: '
      READ(*,*)NP
      WRITE(*,30)' Enter minimum altitude of ammo storage site (feet): '
      READ(*,*)ALTMIN
      WRITE(*,30)' Enter maximum altitude of ammo storage site (feet): '
      READ(*,*)ALTMAX
      WRITE(*,30)' Enter minimum wind speed (feet/second): '
      READ(*,*)WSMIN
      WRITE(*,30)' Enter maximum wind speed (feet/second): '
      READ(*,*)WSMAX
      WRITE(*,30)' Enter wind direction (0 to 90 deg : 0 is tailwind): '
      READ(*,*)WD
      DW=WD
      WD=WD/B
      WRITE(*,30)' Enter maximum computation distance (feet) (9600 MAX):
     $ '
      READ(*,*)MRA
      MR=INT(MRA/100)*100
      WRITE(*,30)' Enter hazard kinetic energy criterion (ft-lbs): '
      READ(*,*)KE
      WRITE(*,30)' Enter hazard density criterion (frags/sqft): '
      READ(*,*)DC
      WRITE(*,30)' Enter probability of hit criterion: '
      READ(*,*)PC
      IF(RZ.EQ.0)GOTO 410
  403 WRITE(*,'(A\)')' Enter Integer Random Number Seed (1 to 2147483646
     $): '
      READ(*,*)USE

  410 WRITE(*,'(//A)')' Replace PROGRAM Disk in Drive A: With DATA Disk'
      PAUSE
      WRITE(*,'(//A)')' --- FRAGHAZ RUNNING ---'

C  BLOCK 3
C  Print All Essential Conditions for the Run

      OPEN(1,FILE=NAM,STATUS='NEW')
      WRITE(1,*)CHAR(14),'FRAGHAZ'
      WRITE(1,*)'quantity - distance program (fragmenting munitions)'
      WRITE(1,'(///A,A)')' Source of frag data: ',Q
      WRITE(1,'(A,A)')' Output file: ',NAM
      WRITE(1,*)'Target description: ',TS
      WRITE(1,'(1X,2(A,F4.2))')'Minimum soil constant= ',SCMIN,'     Max
     $imum soil constant= ',SCMAX
      IF(RZ.EQ.1)THEN
              WRITE(1,*)'MONTE-CARLO OPTION'
      ELSE
              WRITE(1,*)'FULL FACTORIAL OPTION'
      ENDIF
      WRITE(1,'(/A)')' 3-D fragment trajectories, 3-D man, 2-D wind'
      WRITE(1,*)'CD is a function of fragment max to avg presented area
```

```
     $ratio'
      WRITE(1,*)'Run contains fragment ricochet routine'
      WRITE(1,*)'Variable air density, altitude, and sound speed'
      WRITE(1,'(A,I3,A)')' Ejection zone size= ',INT(ES),' degrees'
      WRITE(1,'(A,I2,A)')' Azimuth sector size= ',AS,' degrees'
      WRITE(1,'(A,I6)')' Number of units or interaction areas= ',N4
      WRITE(1,'(A,I3)')' Number of fragment multipliers= ',X5
      WRITE(1,'(A,F5.1,A)')' Fragment hazard criterion= ',KE,' ft-lbs'
      WRITE(1,'(A,I2)')' Percentile= ',PCT
      IF(RZ.EQ.1.)THEN
             WRITE(1,'(A,I10)')' MONTE CARLO SEED= ',IDINT(USE)
           Y=RND(USE)
           UDUM=0D0
C  From this point on call function RND with dummy argument UDUM
      ENDIF
      WRITE(1,'(A,F9.3,A)')' Minimum altitude of ammo storage site= ',AL
     $TMIN,' feet'
      WRITE(1,'(A,F9.3,A)')' Maximum altitude of ammo storage site= ',AL
     $TMAX,' feet'
      WRITE(1,'(A,F6.2,A)')' Height of ammo stack= ',HS,' feet'
      WRITE(1,'(A,F6.2,A)')' Stack inert ground standoff= ',SIGS,' feet'
      WRITE(1,'(A,I5)')' Number of fragments= ',NF
      WRITE(1,'(A,I4,A)')' Maximum computation range: ',MR,' feet'
      WRITE(1,'(A,F7.2,A,F7.2,A,F7.2)')' Dimensions of the target (feet)
     $: HM=',HM,'  WM=',WM,'  DM=',DM
      WRITE(1,'(A,F9.7,A)')' Hazard density criterion= ',DC,' frags/sqft
     $'
      WRITE(1,'(A,F9.7)')' Hazard probability of hit criterion= ',PC
      WRITE(1,'(A,F6.2,A)')' Minimum wind speed= ',WSMIN,' feet/second'
      WRITE(1,'(A,F6.2,A)')' Maximum wind speed= ',WSMAX,' feet/second'
      WRITE(1,'(A,F6.2,A//)')' Wind direction= ',DW,' deg (0=tailwind)'

C  BLOCK 4
C  Headings and Number Formats for Output Tables

  870 FORMAT(1X,'FRAG',6X,'E',9X,'WT',6X,'A/M',6X,'IV',5X,'CD',4X,'DISTN
     $',7X,'VF',6X,'KE',6X,'TOF',6X,'EF',2X,'RANGE',4X,'XRN',5X,'XA',3X,
     $'XD',7X,'AR',5X,'HO',3X,'RB'/)
  880 FORMAT(1X,I4,4X,F6.2,3X,F7.1,3X,F5.2,3X,I5,3X,F4.2,3X,I5,3X,F6.1,3
     $X,F6.1,3X,F5.2,3X,F5.1,2X,I5,3X,I4,3X,F4.1,3X,I2,3X,F6.2,2X,F5.2,3
     $X,I2)
  890 FORMAT(' Distance',17X,'Total',30X,'Hazard',20X,'------ Total Numbe
     $r of Final Ground Impacts ------')
  900 FORMAT('  (feet)',7X,'Total',5X,'Density',7X,'Total',6X,'Hazard',5
     $X,'Density',6X,'Hazard',19X,I2,' Degree Azimuth Sector')
  910 FORMAT(' From',3X,'To',7X,'No.',5X,'Frags/sqft',5X,'P-hit',8X,'No.
     $',4X,'Frags/sqft',5X,'P-hit',16X,'Min',12X,'Avg',13X,'Max')
  920 FORMAT(1X,I4,2X,I4,4X,F7.2,3X,F10.6,3X,F8.6,4X,F7.2,3X,F10.6,3X,F8
     $.6,10X,F8.2,7X,F8.2,8X,F8.2)
  970 FORMAT(' HAZARD    ----------------------------------- NUMBER OF UNI
     $TS TO JUST EXCEED ---------------------------------------')
  940 FORMAT(' DISTANCE   -------------- DENSITY CRITERION --------------',
     $10X,'--------------- P-HIT CRITERION ---------------')
  950 FORMAT(' (FEET)',10X,'MIN',9X,I2,'%',9X,'50%',9X,'MAX',16X,'MIN',9
     $X,I2,'%',9X,'50%',9X,'MAX')
  960 FORMAT(2X,I4,5X,F9.2,3X,F9.2,3X,F9.2,3X,F9.2,10X,F9.2,3X,F9.2,3X,F
```

```
     $9.2,3X,F9.2)
  980 FORMAT(16X,'Hazard Density Criterion= ',F7.6,' frag/sqft',6X,'Haza
     $rd P-hit Criterion= ',F5.3/)
  982 FORMAT(' Distance ----------- Hazard Density (Frags/sqft) ---------
     $--          ----------- Hazard Probability of Hit ----------')
  984 FORMAT(1X,'(feet)',9X,'Max',10X,I2,'%',10X,'50%',10X,'Min',16X,'Ma
     $x',9X,I2,'%',9X,'50%',9X,'Min')
  986 FORMAT(2X,I4,5X,F10.6,3X,F10.6,3X,F10.6,3X,F10.6,11X,F8.6,4X,F8.6,
     $4X,F8.6,4X,F8.6)

C  BLOCK 5
C  Read Fragmentation Data
C  If applicable. read Full Factorial Data

      OPEN(2,FILE=Q)
      READ(2,*)(Y2(I),I=1,X5)
      WRITE(1,*)'Fragment multipliers'
      WRITE(1,'(9(2X,F6.5))')(Y2(I),I=1,X5)
      DO 1050 I=1,X5
      Y2(I)=Y2(I)*FLOAT(AS)
 1050 CONTINUE
      DO 1120 F=1,NF
      READ(2,*)PA,FW(F),AM(F),IV(F),AR2(F)
      IE(F)=90.0-PA
      AE(F)=IE(F)
 1120 CONTINUE
      IF (RZ.EQ.0) THEN
             WRITE(1,'(//1X,A)')'FACTOR LEVELS'
             H9(1)='SOIL CONSTANT: '
             H9(2)='HEIGHT OF ORIGIN: '
             H9(3)='ELEVATION ANGLE: '
             H9(4)='INITIAL VELOCITY: '
             H9(5)='DRAG COEFFICIENT: '
             H9(6)='ALTITUDE: '
             H9(7)='WIND SPEED: '
           DO 1129 I=1,7
             WRITE(1,'(1X,A\)')H9(I)
           READ(2,*,ERR=1128)(FL(I,J),J=1,25)
 1128        WRITE(1,'(25(F8.4))')(FL(I,T),T=1,J-1)
           NL(I)=J-1
 1129      CONTINUE
           NR=NL(1)*NL(2)*NL(3)*NL(4)*NL(5)*NL(6)*NL(7)
           IF (NR.GT.100) THEN
                    WRITE(*,*)'MAX NO. OF TREATMENTS = 100'
           STOP
           ENDIF
      ENDIF
      CLOSE(2)
      IF(RZ.EQ.1)THEN
             WRITE(1,'(/A,I3)')' NO. OF REPLICATIONS = ',INT(NR)
             WRITE(1,'(A,I3//)')' NO. OF REPLICATIONS PRINTED = ',NP
      ELSE
             WRITE(1,'(/A,I3)')' NO. OF TREATMENTS = ',INT(NR)
             WRITE(1,'(A,I3//)')' NO. OF TREATMENTS PRINTED = ',NP
      ENDIF

```

```
D Line# 1      7                          Microsoft FORTRAN77 V3.31 August 1985
         C  BLOCK 6
         C  Begin Replication or Treatment Loop - Set Conditions

               MR=MR/100


         C  Initialize Probability of Not Hitting the Target

               DO 1158 T=1,INT(NR)
1              DO 1159 R=1,MR+1
2              PX(T,R)=1.
2         1159 CONTINUE
1         1158 CONTINUE

               T=0
               IF(RZ.EQ.0)GOTO 1162
          1160 T=T+1
               IF(T.GT.NR)GOTO 3570
               GOTO 1170

          1162 F1=0
          1163 F1=F1+1
               IF(F1.GT.NL(1))GOTO 3570
               F2=0
          1164 F2=F2+1
               IF(F2.GT.NL(2))GOTO 1163
               F3=0
          1165 F3=F3+1
               IF(F3.GT.NL(3))GOTO 1164
               F4=0
          1166 F4=F4+1
               IF(F4.GT.NL(4))GOTO 1165
               F5=0
          1167 F5=F5+1
               IF(F5.GT.NL(5))GOTO 1166
               F6=0
          1168 F6=F6+1
               IF(F6.GT.NL(6))GOTO 1167
               F7=0
          1169 F7=F7+1
               IF(F7.GT.NL(7))GOTO 1168
               T=T+1

            50 FORMAT(31X,A,I3,A/)
          1170 IF(RZ.EQ.0)THEN
                     WRITE(1,50)'TREATMENT ( ',T,' )'
                   BQ=SCMIN+(SCMAX-SCMIN)*FL(1,F1)
                   ALT=ALTMIN+(ALTMAX-ALTMIN)*FL(6,F6)
                   WS=WSMIN+(WSMAX-WSMIN)*FL(7,F7)
               ELSE
                     WRITE(1,50)'REPLICATION ( ',T,' )'
                   BQ=SCMIN+(SCMAX-SCMIN)*RND(UDUM)
                   ALT=ALTMIN+(ALTMAX-ALTMIN)*RND(UDUM)
                   WS=WSMIN+(WSMAX-WSMIN)*RND(UDUM)
               ENDIF
```

```
        IF((WS.EQ.0.).OR.(DW.EQ.0.))THEN
             EZ=0
             XL=4
        ELSE
             EZ=1
             XL=6
        ENDIF

        WRITE(1,'(1X,A,F5.3,2X,A,F9.3,A,2X,A,F7.3,A)')'Soil constant= ',BO
       $,'Altitude= ',ALT,' feet','Wind speed= ',WS,' feet/second'
        WRITE(1,*)CHAR(15)
        WRITE(1,870)
        DO 1300 R=1,MR+1
1
1       PT(R)=1.
1       PH(R)=1.
1  1300 CONTINUE

   C  BLOCK 7
   C  Begin Fragment Loop - Set Height of Origin and Elevation Angle

        DO 3450 F=1,NF
1       RB=0
1       IF(RZ.EQ.0)THEN
1            HO=SIGS+FL(2,F2)*(HS-SIGS)
1            E=(AE(F)+ES*FL(3,F3))/B
1       ELSE
1            HO=SIGS+(HS-SIGS)*RND(UDUM)
1            E=(AE(F)+ES*RND(UDUM))/B
1       ENDIF
1       XE=E*B
1       YE=XE
1
1       IF(HO.GE.HM)THEN
1            CY=1
1       ELSE
1            CY=0
1       ENDIF
1
1  C  BLOCK 8
1  C  Set Remaining Initial Conditions for Current Fragment
1
1       FG=FW(F)/K9
1       RL=0.
1
1       IF(XE.GT.89.99)THEN
1            XE=89.99
1            E=89.99/B
1            YE=89.99
1       ELSEIF((XE.LT.0.01).AND.(XE.GE.0.))THEN
1            XE=0.01
1            E=0.01/B
1            YE=0.01
1       ELSEIF((XE.LT.0.).AND.(XE.GT.-0.01))THEN
1            XE=-0.01
1            E=-0.01/B
```

```
D Line# 1     7                       Microsoft FORTRAN77 V3.31 August 1985
                 YE=-0.01
            ENDIF
            CALL INTSTP(XE,HO,E,XD)

            IF(RZ.EQ.0)THEN
                 V=IV(F)+IV(F)*0.035*FL(4,F4)
            ELSE
                 DD=SQRT(-2.*LOG(RND(UDUM)))
                 EE=BB*RND(UDUM)
                 N1=DD*COS(EE)
                 N2=DD*SIN(EE)
                 V=IV(F)+IV(F)*0.035*N1
            ENDIF

            XV=V

      C  BLOCK 9
      C  Establish Drag Parameters

            CH=1.75*AR2(F)-1.27
            CL=0.66*AR2(F)-0.26
            IF(RZ.EQ.0)THEN
                 D1=CL+(CH-CL)*FL(5,F5)
            ELSE
                 D1=CL+(CH-CL)*RND(UDUM)
            ENDIF
            D2=D1+0.2
            D3=D1+0.65
            D4=D1+0.5

      C  BLOCK 10
      C  Set Initial Conditions for Fragment Trajectory

            DI(1)=0.
            DI(2)=V*COS(E)
            DI(3)=0.
            DI(4)=V*SIN(E)
            DI(5)=HO
            DI(6)=0
            DI(7)=0

      C  BLOCK 11
      C  Begin Trajectory Calculations

       2140 V=SQRT(DI(2)*DI(2)+DI(4)*DI(4)+DI(6)*DI(6))
            DLT=XD/V
            LE=ABS(ATAN(DI(4)/SQRT(DI(2)*DI(2)+DI(6)*DI(6))))
            IF(LE.LT.(0.001/B))LE=0.001/B

      C  BLOCK 12
      C  Compute Special Time Increment if Conditions Dictate

            IF(DI(5).LE.HM)THEN
                 IF((DI(4).LT.0.).AND.((DI(5)/SIN(LE)).LT.(XD+HM-0.2)))DLT=(
           *DI(5)/SIN(LE)-HM+0.2)/V
                 IF((DI(4).LT.0.).AND.((DI(5)/SIN(LE)).LT.HM))DLT=(DI(5)/SIN
```

```
     $(LE)-0.3)/V
           IF((DI(4).LT.0.).AND.((DI(5)/SIN(LE)).LT.0.4))DLT=DI(5)/SIN
     $(LE)/V+0.000002
      ELSEIF((DI(4).LT.0.).AND.(DI(5).LT.(XD+12.)))THEN
           IF(.NOT.(((DI(5)-HM)/SIN(LE)).GE.(XD+HM-0.2)))DLT=((DI(5)-H
     $M)/SIN(LE)-HM+0.2)/V
           IF(((DI(5)-HM)/SIN(LE)).LT.HM)DLT=((DI(5)-HM)/SIN(LE)-0.3)/
     $V
           IF(((DI(5)-HM)/SIN(LE)).LT.0.4)DLT=(DI(5)-HM)/SIN(LE)/V+0.0
     $00002
      ENDIF
      IF((V.LT.100.).AND.(DI(4).GT.-30.).AND.(DLT.GT.0.1))DLT=0.1
      IF((RB.GT.1).AND.(V.LT.150.).AND.(DLT.GT.0.08))DLT=0.08
      DI(1)=DI(1)+DLT

C   BLOCK 13
C   Begin Runge-Kutta Routine and Calculate Wind Effects

      DO 2920 I=1,4
      IF(I.LT.3)THEN
           KM=0.5
      ELSE
           KM=1.
      ENDIF
      IF(.NOT.(WS.GT.0.))THEN
           VP=SQRT(DI(2)*DI(2)+DI(4)*DI(4))
           AY=ATAN(DI(4)/DI(2))
           AX=PI/2-AY
      ELSEIF(DW.EQ.0.)THEN
           VXP=DI(2)-WS
           VYP=DI(4)
           VP=SQRT(VXP*VXP+VYP*VYP)
           AY=ATAN(VYP/ABS(VXP))
           AX=ATAN(VXP/ABS(VYP))
           ELSE
           VXP=DI(2)-WS*COS(WD)
           VYP=DI(4)
           VZP=WS*SIN(WD)-DI(6)
           VP=SQRT(VXP*VXP+VYP*VYP+VZP*VZP)
           AY=ATAN(VYP/SQRT(VXP*VXP+VZP*VZP))
           AX=ATAN(VXP/SQRT(VYP*VYP+VZP*VZP))
           AZ=ATAN(VZP/SQRT(VXP*VXP+VYP*VYP))
      ENDIF

C   BLOCK 14
C   Calculate Air Density, Mach Number, and CD

      RO=K3*EXP(-((DI(5)+ALT)+DI(4)*DLT/2)/K4)
      MN=VP/(VS*EXP(-((DI(5)+ALT)+DI(4)*DLT/2)/K1))
      IF(MN.GE.M1)THEN
           IF(MN.GE.M2)THEN
           IF(MN.GE.M3)THEN
           CD=D4
           ELSE
           CD=D3-0.15/(M3-M2)*(MN-M2)
           ENDIF
```

```
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D Line# 1      7                     Microsoft FORTRAN77 V3.31 August 1985
2                   ELSE
2                   CD=D3-0.45/(M2-M1)*(M2-MN)
2                   ENDIF
2             ELSE
2                   CD=D2-0.2/(M1-0.1)*(M1-MN)
2             ENDIF
2
2     C  BLOCK 15
2     C  Calculate Velocities and Accelerations
2
2             KK=RO*VP*VP*CD*AM(F)/K5
2             DO(2)=-KK*SIN(AX)
2             DO(3)=DI(2)
2             DO(4)=-KK*SIN(AY)-G
2             DO(5)=DI(4)
2             IF(EZ.NE.0)THEN
2                   DO(6)=KK*SIN(AZ)
2                   DO(7)=DI(6)
2             ENDIF
2
2     C  BLOCK 16
2     C  Basic Runge-Kutta Calculations
2
2             DO 2910 J=2,XL,2
3             IF(.NOT.(I.GT.1))DS(J)=DI(J)
3             XK(I,J)=DO(J)*DLT
3             IF(I.EQ.4)THEN
3                   DI(J)=DS(J)+(XK(1,J)+2*XK(2,J)+2*XK(3,J)+XK(4,J))/6.
3                   DI(J+1)=DI(J+1)+DLT*(DS(J)+(XK(1,J)+XK(2,J)+XK(3,J))/6.)
3             ELSE
3                   DI(J)=DS(J)+XK(I,J)*KM
3             ENDIF
3        2910 CONTINUE
2        2920 CONTINUE
1
1     C  BLOCK 17
1     C  Check Location of Fragment and Make Hazard Volume Calculations
1     C  if Applicable
1
1             R=INT(SQRT(DI(3)*DI(3)+DI(7)*DI(7))/100)+1
1             IF(R.GT.MR)R=MR+1
1             IF(DI(5).GT.HM)THEN
1                   CX=1
1             ELSE
1                   CX=0
1             ENDIF
1             IF(CX.NE.1)THEN
1                   GOTO 3020
1             ELSEIF(CY.NE.1)THEN
1                   CY=1
1                   DF=(DI(5)-HM)/TAN(LE)
1                   R=INT((SQRT(DI(3)*DI(3)+DI(7)*DI(7))-DF)/100)+1
1                   IF(R.GT.MR)R=MR+1
1             ELSE
1                   GOTO 5170
1             ENDIF
```

```
D Line# 1     7                    Microsoft FORTRAN77 V3.31 August 1985
1
1   3020 IF(R.NE.RL)THEN
1              P=0.
1              S1=0.
1              S2=1.
1              S3=0.
1              S4=1.
1              S5=1.
1              S6=0.
1              TA=0.
1              MA=0.
1              XP=0.
1              ZP=0.
1              ZZP=0.
1              DX=0.
1              GX=0.
1              HX=0.
1         ENDIF
1
1      C  BLOCK 18
1      C  Routine for Accumulating Number of Fragments, Density, and
1      C  Probability of Not Hitting the Target
1
1         NX=FLOAT(N4)*Y2(INT((90-IE(F))/ES))
1         P=P+1
1         IF(R.EQ.MR+1)GOTO 5440
1
1
1
1         IF(P.GT.1)GOTO 5250
1         NT(R)=NT(R)+NX/NR
1   5250  LE=ABS(ATAN(DI(4)/SQRT(DI(2)*DI(2)+DI(6)*DI(6))))
1         TA=PW*(R*R-(R-1)*(R-1))*SIN(LE)+AS*DR*((R*100)-50)*HM*COS(LE)
1         IF(DI(4).LE.0)THEN
1              MA=(HM*COS(LE)+DM*SIN(LE))*WM
1         ELSE
1              MA=HM*COS(LE)*WM
1         ENDIF
1         DX=(DX*(P-1)+NX/TA)/P
1         DT(R)=DT(R)+DX/NR-S1
1         S1=DX/NR
1         XP=(XP*(P-1)+EXP(-NX*MA/TA))/P
1         PT(R)=PT(R)*XP/S2
1         S2=XP
1         CKE=FG*(DI(2)*DI(2)+DI(4)*DI(4)+DI(6)*DI(6))
1         IF(CKE.LT.KE)NX=0
1         GX=(GX*(P-1)+NX)/P
1         NH(R)=NH(R)+GX/NR-S6
1         S6=GX/NR
1         HX=(HX*(P-1)+NX/TA)/P
1         DH(R)=DH(R)+HX/NR-S3
1         D6H(T,R)=D6H(T,R)+HX-S3*NR
1         S3=HX/NR
1         ZP=(ZP*(P-1)+EXP(-NX*MA/TA))/P
1         ZZP=(ZZP*(P-1)+EXP(-NX/FLOAT(N4)*MA/TA))/P
1         PH(R)=PH(R)*ZP/S4
```

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D Line# 1      7                          Microsoft FORTRAN77 V3.31 August 1985
1             S4=ZZP
1             PX(T,R)=PX(T,R)*ZZP/S5
1             S5=ZZP
1        5440 RL=R
1        5170 IF(DI(5).GT.0.)GOTO 2140
1
1       C  BLOCK 19
1       C  Check for Ricochet and Compute New Initial Conditions
1       C  for Ricochetting Fragment
1
1             E=ATAN(DI(4)/SQRT(DI(2)*DI(2)+DI(6)*DI(6)))
1             VR=SQRT(DI(2)*DI(2)+DI(4)*DI(4)+DI(6)*DI(6))
1             IF  (RB.GT.6)GOTO 3330
1             IF(((ABS(E*B)).GE.(10.8*BQ**0.38)).OR.(VR.LT.20.))GOTO 3330
1             EY=ABS(E*B)
1             VQ(1)=-.01597*EY*EY+.02156*EY+.9617
1             VQ(2)=-.00861*EY*EY+.00692*EY+.96302
1             VQ(3)=-.00387*EY*EY-.00414*EY+.95592
1             VQ(4)=-.00342*EY*EY-.00097*EY+.9409
1             VQ(5)=-.00243*EY*EY-.0052*EY+.9308
1             VQ(6)=-.00188*EY*EY-.00821*EY+.93802
1             EQ(1)= .13829*EY*EY-.98645*EY+2.8155
1             EQ(2)= .08549*EY*EY-.78423*EY+2.9012
1             EQ(3)= .07515*EY*EY-.73919*EY+3.1056
1             EQ(4)= .02142*EY*EY-.37397*EY+2.7858
1             EQ(5)= .01707*EY*EY-.32521*EY+2.8092
1             EQ(6)= .01369*EY*EY-.2958*EY+2.8262
1             IF(.NOT.((BQ.GE.0.25).AND.(BQ.LT.0.5)))GOTO 5680
1             QV=VQ(1)+(BQ-.25)/.25*(VQ(2)-VQ(1))
1             QE=EQ(1)+(BQ-.25)/.25*(EQ(2)-EQ(1))
1             GOTO 5820
1        5680 IF(.NOT.((BQ.GE.0.5).AND.(BQ.LT.1.)))GOTO 5720
1             QV=VQ(2)+(BQ-.5)/.5*(VQ(3)-VQ(2))
1             QE=EQ(2)+(BQ-.5)/.5*(EQ(3)-EQ(2))
1             GOTO 5820
1        5720 IF(.NOT.((BQ.GE.1.).AND.(BQ.LT.2.)))GOTO 5760
1             QV=VQ(3)+(BQ-1)*(VQ(4)-VQ(3))
1             QE=EQ(3)+(BQ-1)*(EQ(4)-EQ(3))
1             GOTO 5820
1        5760 IF(.NOT.((BQ.GE.2.).AND.(BQ.LT.3.)))GOTO 5800
1             QV=VQ(4)+(BQ-2)*(VQ(5)-VQ(4))
1             QE=EQ(4)+(BQ-2)*(EQ(5)-EQ(4))
1             GOTO 5820
1        5800 QV=VQ(5)+(BQ-3)*(VQ(6)-VQ(5))
1             QE=EQ(5)+(BQ-3)*(EQ(6)-EQ(5))
1        5820 VA=QV*VR
1             EA=-E*QE
1             XE=EA*B
1             IF  (VA.LT.20.)GOTO 3330
1             RB=RB+1
1             DI(4)=VA*SIN(EA)
1             IF((DW.EQ.0.).OR.(WS.EQ.0.))THEN
1                   DI(2)=VA*COS(EA)
1                   DI(6)=0.
1             ELSE
1                   AQ=ATAN(DI(2)/DI(6))
```

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D Line# 1      7                         Microsoft FORTRAN77 V3.31 August 1985
1                   DI(2)=VA*COS(EA)*SIN(AQ)
1                   DI(6)=VA*COS(EA)*COS(AQ)
1              ENDIF
1        3250  IF(VA.LT.(20.))GOTO 3330
1              CALL INTSTP(XE,HO,E,XD)
1              CY=0
1              GOTO 2140

1          C   BLOCK 20
1          C   Compute and Print Initial and Final Conditions
1          C   for Current Fragment Trajectory

1        3330  DN=SQRT(DI(3)*DI(3)+DI(7)*DI(7))
1              XR=DI(7)
1              RN=SQRT(DN*DN-XR*XR)
1              R=INT(DN/100+1)
1              IF(R.GT.MR)THEN
1                   R=MR+1
1                   TJ=TJ+1
1              ENDIF
1              XN(R)=XN(R)+FLOAT(N4)*Y2(INT((90-IE(F))/ES))/NR
1              YN(T,R)=YN(T,R)+FLOAT(N4)*Y2(INT((90-IE(F))/ES))
1              XA=ATAN(XR/RN)*B
1              VF=SQRT(DI(2)*DI(2)+DI(4)*DI(4)+DI(6)*DI(6))
1              CKE=FW(F)*VF*VF/450436.
1              IF(CKE.GT.9999.9)CKE=9999.9
1              IF(.NOT.((T.LE.NP).AND.(NP.GT.0.)))GOTO 3450
1              WRITE(1,880)F,YE,FW(F),AM(F),NINT(XV),D1,NINT(DN),VF,CKE,DI(1),-(E
1             $*B),NINT(RN),NINT(XR),XA,NINT(XD),AR2(F),HO,RB
1        3450  CONTINUE
               DO 3490 R=1,MR
1              TP(R)=TP(R)+(1-PT(R))/NR
1              HP(R)=HP(R)+(1-PH(R))/NR
1        3490  CONTINUE
               WRITE(1,*)CHAR(18)

               IF(RZ.EQ.1)GOTO 1160

               GOTO 1169

           C   BLOCK 21 - Sort for Max, Min, and Percentiles

           C   BLOCK 21A
           C   Max and Min Number of Final Impacts

         3570  DO 3700 R=1,MR
1              IF(NR.GT.1)GOTO 3620
1              N8MIN(R)=YN(1,R)
1              N9MAX(R)=YN(1,R)
1              GOTO 3700
1        3620  DO 3680 I=1,INT(NR)-1
2              DO 3670 J=I,1,-1
3              IF(YN(J,R).LE.YN(J+1,R))GOTO 3680
3              T5=YN(J,R)
3              YN(J,R)=YN(J+1,R)
3              YN(J+1,R)=T5
```

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D Line# 1      7                       Microsoft FORTRAN77 V3.31 August 1985
3        3670 CONTINUE
2        3680 CONTINUE
1             N8MIN(R)=YN(1,R)
1             N9MAX(R)=YN(INT(NR),R)
1        3700 CONTINUE

          C  BLOCK 21B
          C  Max, Min and Percentile Hazard Density

              DO 3900 R=1,MR
1             IF(NR.GT.1)GOTO 3800
1             D7MIN(R)=D6H(1,R)
1             D8MAX(R)=D6H(1,R)
1             D5(R)=D6H(1,R)
1             D9(R)=D6H(1,R)
1             GOTO 3900
1        3800 DO 3850 I=1,INT(NR)-1
2             DO 3840 J=I,1,-1
3             IF(D6H(J,R).LE.D6H(J+1,R))GOTO 3850
3             T5=D6H(J,R)
3             D6H(J,R)=D6H(J+1,R)
3             D6H(J+1,R)=T5
3        3840 CONTINUE
2        3850 CONTINUE
1             D7MIN(R)=D6H(1,R)
1             D8MAX(R)=D6H(INT(NR),R)
1             P5 = NR * .5
1             P9 = NR * PCTD
1             IF(P5.NE.INT(P5)) P5 = INT(P5) + 1.
1             IF(P9.NE.INT(P9)) P9 = INT(P9) + 1.
1             IF(P5.LT.1.) P5 = 1.
1             IF(P9.LT.1.) P9 = 1.
1             D5(R) = D6H(INT(P5),R)
1             D9(R) = D6H(INT(P9),R)
1        3900 CONTINUE

          C  BLOCK 21C
          C  Sort Probability of Not Hitting for a Single Unit

              DO 4020 R=1,MR
1             IF (NR.EQ.1.)GOTO 4020
1             DO 4010 I=1,INT(NR)-1
2             DO 4013 J=I,1,-1
3             IF (PX(J,R).LE.PX(J+1,R))GOTO 4010
3             T5=PX(J,R)
3             PX(J,R)=PX(J+1,R)
3             PX(J+1,R)=T5
3        4013 CONTINUE
2        4010 CONTINUE
1
1
1
1        4020 CONTINUE

          C  BLOCK 22
          C  Compute and Print Average Number Density and P-Hit; and Number of
```

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D Line# 1      7                             Microsoft FORTRAN77 V3.31 August 1985
       C  Final Impacts for Given Distance Increment and Number of Units

                DO 5130 RI=100,400,100
1               RI2=RI/100
1               DO 4280 R=1,MR/RI2
2               DO 4260 J=1,RI2
3               K=RI2*(R-1)+J
3               KW=K-.5
3               SUM=SUM+KW
3               TN(R)=TN(R)+NT(K)
3               TD(R)=(TD(R)*(SUM-KW)+DT(K)*KW)/SUM
3               FTP(R)=(FTP(R)*(SUM-KW)+TP(K)*KW)/SUM
3               HN(R)=HN(R)+NH(K)
3               HD(R)=(HD(R)*(SUM-KW)+DH(K)*KW)/SUM
3
3
3
3
3               X7DMIN(R)=(X7DMIN(R)*(SUM-KW)+D7MIN(K)*KW)/SUM
3               X8DMAX(R)=(X8DMAX(R)*(SUM-KW)+D8MAX(K)*KW)/SUM
3               X5D(R) = (X5D(R) * (SUM - KW) + D5(K) * KW) / SUM
3               X9D(R)=(X9D(R)*(SUM-KW)+D9(K)*KW)/SUM
3               FHP(R)=(FHP(R)*(SUM-KW)+HP(K)*KW)/SUM
3
3               X7PMIN(R)=(X7PMIN(R)*(SUM-KW)+(1-PX(INT(NR),K)**FLOAT(N4))*KW)/SUM
3               X8PMAX(R)=(X8PMAX(R)*(SUM-KW)+(1-PX(1,K)**FLOAT(N4))*KW)/SUM
3
3
3
3
3
3
3
3               P5 = NR * .5 + 1.
3               P9 = NR * (1. - PCTD) + 1.
3               IF(P5.NE.INT(P5)) P5 = INT(P5)
3               IF(P9.NE.INT(P9)) P9 = INT(P9)
3               IF(PCTD.EQ.0.0) P9 = NR
3               X5P(R) = (X5P(R)*(SUM-KW)+(1.-PX(INT(P5),K)**FLOAT(N4))*KW)/SUM
3               X9P(R) = (X9P(R)*(SUM-KW)+(1.-PX(INT(P9),K)**FLOAT(N4))*KW)/SUM
3               TI(R)=TI(R)+XN(K)
3               T8MIN(R)=T8MIN(R)+N8MIN(K)
3               T9MAX(R)=T9MAX(R)+N9MAX(K)
3          4260 CONTINUE
2               SUM=0.
2
2
2          4280 CONTINUE
1               RI2=RI2*100
1               MR=MR*100
1               WRITE(1,*)CHAR(15)
1               WRITE(1,'(/10X,A,5X,A,I4,A,5X,A,I5/)')'TABLE 1','Increment = ',RI,
1              $' feet','Number of Units= ',N4
1               WRITE(1,890)
1               WRITE(1,900)AS
1               WRITE(1,910)
```

```
      DO 4380 R=1,MR/RI
      WRITE(1,920)RI*(R-1),RI*R,TN(R),TD(R),FTP(R),HN(R),HD(R),FHP(R),T8
     $MIN(R),TI(R),T9MAX(R)
 4380 CONTINUE
      WRITE(1,'(/7X,A,I4,A,I4//)')'Number of trajectories with distance
     $greater than ',MR,' feet=',TJ

C  BLOCK 23
C  Print Hazard Density and Probability of Hit for
C  Number of Units Selected

      RI2=RI/100
      MR=MR/100
      WRITE(1,'(//10X,A,10X,A,I4,A,10X,A,I5//)')'TABLE 2','Increment= ',
     $RI,' feet','Number of Units= ',N4
      WRITE(1,982)
      WRITE(1,984)PCT,PCT
      DO 4450 R=1,MR/RI2
      WRITE(1,986)RI*(2*R-1)/2,X8DMAX(R),X9D(R),X5D(R),X7DMIN(R),X8PMAX(
     $R),X9P(R),X5P(R),X7PMIN(R)
 4450 CONTINUE

C  BLOCK 24
C  Compute and Print Number of Units Required to Just Exceed
C  Hazard Density and P-Hit Criteria

      WRITE(1,'(//20X,A,10X,A,I4,A/)')'TABLE 3','Increment= ',RI,' feet'
      WRITE(1,970)
      WRITE(1,940)
      WRITE(1,950)PCT,PCT
      DO 4610 R=1,MR/RI2
      IF(X8DMAX(R).EQ.0.0) THEN
        Y7DMIN(R) = 999999
      ELSE
        Y7DMIN(R) = DC/X8DMAX(R)*FLOAT(N4) + .01
      ENDIF
      IF(X9D(R).EQ.0.0) THEN
        Y9D(R) = 999999
      ELSE
        Y9D(R) = DC/X9D(R)*FLOAT(N4) + .01
      ENDIF
      IF(X5D(R).EQ.0.0) THEN
        Y5D(R) = 999999
      ELSE
        Y5D(R) = DC/X5D(R)*FLOAT(N4) + .01
      ENDIF
      IF(X7DMIN(R).EQ.0.0) THEN
        Y8DMAX(R) = 999999
      ELSE
        Y8DMAX(R) = DC/X7DMIN(R)*FLOAT(N4) + .01
      ENDIF


 4610 CONTINUE
      RI2=RI/100
      DO 4860 R=1,MR/RI2
```

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```
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2              DO 4730 J=1,RI2
3              K = RI2 * (R-1) + J
3              KW = K - .5
3              SUM = SUM + KW
3              Z5P(R)=(Z5P(R)*(SUM-KW)+(1.-PX(INT(P5),K))*KW)/SUM
3              Z7PMIN(R) = (Z7PMIN(R) * (SUM - KW) + (1 - PX(INT(NR),K))* KW)/SUM
3              Z8PMAX(R) = (Z8PMAX(R) * (SUM - KW) + (1 - PX(1,K)) * KW) / SUM
3              Z9P(R)=(Z9P(R)*(SUM-KW)+(1.-PX(INT(P9),K))*KW)/SUM
3        4730  CONTINUE
2              SUM=0.
2              IF(Z8PMAX(R).EQ.0.0) THEN
2                NP2(1,R) = 999999
2              ELSEIF(Z8PMAX(R).EQ.1.) THEN
2                NP2(1,R) = .01
2              ELSE
2                NP2(1,R)=LOG(1.-PC)/LOG(1.-Z8PMAX(R)) + .01
2
2              ENDIF
2              IF(Z9P(R).EQ.0.0) THEN
2                NP2(2,R) = 999999
2              ELSEIF(Z9P(R).EQ.1.) THEN
2                NP2(2,R) = .01
2              ELSE
2                NP2(2,R)=LOG(1.-PC)/LOG(1.-Z9P(R)) + .01
2
2              ENDIF
2              IF(Z5P(R).EQ.0.0) THEN
2                NP2(3,R) = 999999
2              ELSEIF(Z5P(R).EQ.1.) THEN
2                NP2(3,R) = .01
2              ELSE
2                NP2(3,R)=LOG(1.-PC)/LOG(1.-Z5P(R)) + .01
2
2              ENDIF
2              IF(Z7PMIN(R).EQ.0.0) THEN
2                NP2(4,R) = 999999
2              ELSEIF(Z7PMIN(R).EQ.1.) THEN
2                NP2(4,R) = .01
2              ELSE
2                NP2(4,R)=LOG(1.-PC)/LOG(1.-Z7PMIN(R)) + .01
2
2              ENDIF
2
2        4860  CONTINUE
1              RI2=RI2*100
1              MR=MR*100
1              DO 4990 R=1,MR/RI
2              WRITE(1,960)RI*(2*R-1)/2,Y7DMIN(R),Y9D(R),Y5D(R),Y8DMAX(R),NP2(1,R
2             $),NP2(2,R),NP2(3,R),NP2(4,R)
2        4990  CONTINUE
1              WRITE(1,*)
1              WRITE(1,'(17X,A)')'The 999999.00 entries signify that the number o
1             $f units required is infinite,'
1              WRITE(1,'(29X,A)')'that is, the Hazard Density and P-hit are both
1             $zero.'
1              DO 5080 R=1,MR/100
```

```
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2    953            TN(R)=0.
2    954            HN(R)=0.
2    955            TI(R)=0.
2    956            T8MIN(R)=0.
2    957            T9MAX(R)=0.
2    958    5080  CONTINUE
1    959            WRITE(1,980)DC,PC
1    960            MR=MR/100
1    961    5130  CONTINUE
     962            WRITE(1,*)CHAR(18)
     963            CLOSE(1)
     964            END

Name      Type            Offset P Class

ABS                                 INTRINSIC
AE        REAL                 0    LARGE
ALT       REAL              1922
ALTMAX    REAL               248
ALTMIN    REAL               244
AM        REAL                 0    LARGE
AQ        REAL              2190
AR2       REAL                 0    LARGE
AS        INTEGER*4           76
ATAN                                INTRINSIC
AX        REAL              2050
AY        REAL              2046
AZ        REAL              2066
B         REAL                60
BB        REAL                68
BQ        REAL              1918
CD        REAL              2078
CH        REAL              2006
CHAR                                INTRINSIC
CKE       REAL              2162
CL        REAL              2010
COS                                 INTRINSIC
CX        INTEGER*4         2090
CY        INTEGER*4         1966
D1        REAL              2014
D2        REAL              2018
D3        REAL              2022
D4        REAL              2026
D5        REAL                 0    LARGE
D6H       REAL                 0    LARGE
D7MIN     REAL             38800    LARGE
D8MAX     REAL             39188    LARGE
D9        REAL             39576    LARGE
DC        REAL               280
DD        REAL              1986
DF        REAL              2094
DH        REAL                28    LARGE
DI        REAL                 0    LARGE
DLT       REAL              2030
DM        REAL                88
DN        REAL              2194
```

```
D Line# 1       7
DO      REAL            0    LARGE
DR      REAL           64
DS      REAL          388    LARGE
DT      REAL            0    LARGE
DW      REAL          264
DX      REAL         2146
E       REAL         1954
EA      REAL         2186
EC      REAL        *****
EE      REAL         1990
EQ      REAL            0    LARGE
ES      REAL           72
EXP                          INTRINSIC
EY      REAL         2170
EZ      INTEGER*4    1930
F       INTEGER*4    1844
F1      INTEGER*4    1876
F2      INTEGER*4    1880
F3      INTEGER*4    1884
F4      INTEGER*4    1888
F5      INTEGER*4    1892
F6      INTEGER*4    1896
F7      INTEGER*4    1900
FG      REAL         1970
FHP     REAL            0    LARGE
FL      REAL          388    LARGE
FLOAT                        INTRINSIC
FTP     REAL         1388    LARGE
FW      REAL         1776    LARGE
G       REAL           48
GX      REAL         2150
H9      CHAR*19       388    LARGE
HD      REAL            0    LARGE
HM      REAL           80
HN      REAL            0    LARGE
HO      REAL         1950
HP      REAL            0    LARGE
HS      REAL          204
HX      REAL         2154
I       INTEGER*4    1832
IDINT                        INTRINSIC
IE      REAL            0    LARGE
INT                          INTRINSIC
IV      REAL         2000    LARGE
J       INTEGER*4    1856
K       INTEGER*4    2274
K1      REAL           32
K3      REAL           36
K4      REAL           40
K5      REAL           44
K9      REAL           52
KE      REAL          276
KK      REAL         2082
KM      REAL         2038
KW      REAL         2278
LE      REAL         2034
```

D Line# 1 7

LOG			INTRINSIC
M1	REAL	16	
M2	REAL	20	
M3	REAL	24	
MA	REAL	2130	
MN	REAL	2074	
MR	INTEGER*4	272	
MRA	REAL	268	
N1	REAL	1994	
N2	REAL	1998	
N4	INTEGER*4	212	
N8MIN	REAL	0	LARGE
N9MAX	REAL	388	LARGE
NAM	CHAR*14	118	
NF	INTEGER*4	220	
NH	REAL	776	LARGE
NINT			INTRINSIC
NL	INTEGER*4	2716	LARGE
NP	INTEGER*4	240	
NP2	REAL	1164	LARGE
NR	REAL	236	
NT	REAL	0	LARGE
NX	REAL	2158	
P	REAL	2098	
P5	REAL	2242	
P9	REAL	2246	
PA	REAL	1852	
PC	REAL	284	
PCT	INTEGER*4	224	
PCTD	REAL	228	
PH	REAL	0	LARGE
PI	REAL	56	
PT	REAL	0	LARGE
PW	REAL	92	
PX	REAL	0	LARGE
Q	CHAR*14	100	
QE	REAL	2178	
QV	REAL	2174	
R	INTEGER*4	1868	
RB	INTEGER*4	1946	
RI	INTEGER*4	2258	
RI2	INTEGER*4	2262	
RL	INTEGER*4	1974	
RN	REAL	2202	
RND	REAL		FUNCTION
RO	REAL	2070	
RZ	INTEGER*4	232	
S1	REAL	2102	
S2	REAL	2106	
S3	REAL	2110	
S4	REAL	2114	
S5	REAL	2118	
S6	REAL	2122	
SCMAX	REAL	200	
SCMIN	REAL	196	
SIGS	REAL	208	

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SIN			INTRINSIC
SQRT			INTRINSIC
SUM	REAL	2282	
T	INTEGER*4	1860	
T5	REAL	2230	
T8MIN	REAL	0	LARGE
T9MAX	REAL	388	LARGE
TA	REAL	2126	
TAN			INTRINSIC
TD	REAL	0	LARGE
TI	REAL	388	LARGE
TJ	INTEGER*4	2206	
TN	REAL	776	LARGE
TP	REAL	1164	LARGE
TS	CHAR*64	132	
UDUM	REAL*8	300	
USE	REAL*8	288	
V	REAL	1982	
VA	REAL	2182	
VF	REAL	2214	
VP	REAL	2042	
VQ	REAL	0	LARGE
VR	REAL	2166	
VS	REAL	28	
VXP	REAL	2054	
VYP	REAL	2058	
VZP	REAL	2062	
WD	REAL	260	
WM	REAL	84	
WS	REAL	1926	
WSMAX	REAL	256	
WSMIN	REAL	252	
X5	INTEGER*4	216	
X5D	REAL	0	LARGE
X5P	REAL	388	LARGE
X7DMIN	REAL	0	LARGE
X7PMIN	REAL	0	LARGE
X8DMAX	REAL	388	LARGE
X8PMAX	REAL	0	LARGE
X9D	REAL	776	LARGE
X9P	REAL	1164	LARGE
XA	REAL	2210	
XD	REAL	1978	
XE	REAL	1958	
XK	REAL	0	LARGE
XL	INTEGER*4	1934	
XN	REAL	112	LARGE
XP	REAL	2134	
XR	REAL	2198	
XV	REAL	2002	
Y	REAL	296	
Y2	REAL	0	LARGE
Y5D	REAL	144	LARGE
Y7DMIN	REAL	0	LARGE
Y8DMAX	REAL	388	LARGE
Y9D	REAL	776	LARGE

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YE       REAL           1962
YN       REAL              0   LARGE
Z5P      REAL              0   LARGE
Z7PMIN   REAL          38800   LARGE
Z8PMAX   REAL          39188   LARGE
Z9P      REAL          39576   LARGE
ZP       REAL           2138
ZZP      REAL           2142


C   BLOCK 25
C   Function Subprogram to Calculate Random Number

          FUNCTION RND(UIX)
          DOUBLE PRECISION UA,UP,UIX,UIY,UB15,UB16,UXHI,UXALO,ULEFTLO,UFHI,
         $UK
          DATA UA/16807.D0/,UB15/32768.D0/,UB16/65536.D0/,UP/2147483647.D0/
          IF(UIX.EQ.0)UIX=UIY
    7000 UXHI=UIX/UB16
          UXHI=UXHI-DMOD(UXHI,1.D0)
          UXALO=(UIX-UXHI*UB16)*UA
          ULEFTLO=UXALO/UB16
          ULEFTLO=ULEFTLO-DMOD(ULEFTLO,1.D0)
          UFHI=UXHI*UA+ULEFTLO
          UK=UFHI/UB15
          UK=UK-DMOD(UK,1.D0)
          UIX=(((UXALO-ULEFTLO*UB16)-UP)+(UFHI-UK*UB15)*UB16)+UK
          IF(UIX.LT.0)UIX=UIX+UP
          UIY=UIX
          RND=INT((UIX*4.656612875D-10)*1D06)/1D06
          IF(RND.EQ.0)GOTO 7000
          RETURN
          END

Name     Type         Offset P Class

DMOD                           INTRINSIC
INT                            INTRINSIC
UA       REAL*8         2314
UB15     REAL*8         2322
UB16     REAL*8         2330
UFHI     REAL*8         2378
UIX      REAL*8            0 *
UIY      REAL*8         2346
UK       REAL*8         2386
ULEFTL   REAL*8         2370
UP       REAL*8         2338
UXALO    REAL*8         2362
UXHI     REAL*8         2354



C   BLOCK 26
C   Subroutine for Selecting Integration Step

          SUBROUTINE INTSTP(XE,HO,E,XD)
```

```
D Line# 1      7                                    Microsoft FORTRAN77 V3.31 August 1985

               IF((XE.LT.0.).AND.((HO/SIN(-E)).GT.60.))THEN
                    XD=50.
               ELSEIF(XE.LT.0.)THEN
                    XD=AINT(HO/SIN(-E)/1.2)
               ELSEIF(XE.LE.70.)THEN
                    XD=AINT(-0.02492*XE*XE+2.20134*XE+18.8306)
               ELSE
                    XD=50.
               ENDIF
          6040 RETURN
               END

Name      Type          Offset P Class

AINT                             INTRINSIC
E        REAL                8 *
HO       REAL                4 *
SIN                              INTRINSIC
XD       REAL               12 *
XE       REAL                0 *


Name      Type            Size   Class

INTSTP                           SUBROUTINE
MAIN                             PROGRAM
RND      REAL                    FUNCTION

  Pass One     No Errors Detected
           1004 Source Lines
```

APPENDIX C

GLOSSARY

The glossary is arranged in alphabetical order. All variables begin with a letter. Second and subsequent characters may be numbers. Numbers precede letters; for example, D3 would precede DA.

There are three types of variables in the glossary which are explained as follows:

Flag - A variable used to indicate a set of alternate states. For example the variable RZ is used to indicate the selection of the MONTE CARLO or FULL FACTORIAL option. When RZ equals 1 then the MONTE CARLO path is followed through the program. When RZ equals 0 the FULL FACTORIAL path is followed.

Index - Used with array variables to designate a particular element in the array. Often the index is used in loops to assign values to the array elements as necessary.

Counter - Used to count the number of times a particular action has occurred and sometimes to designate a particular element in an array. For example, the replication or treatment counter (T) is used to identify the number of the current replication or treatment and also provides an index for such variables as PX (T,R).

Array variables have either one or two indices enclosed by parenthesis. In dimensioning these variables in BLOCK-1, the maximum number of elements permitted is specified. These maximum numbers of elements are explained as follows:

(97) -Maximum number of 100-ft range increments plus 1. The additional element is used to store those trajectories which have ranges greater than the selected maximum computational range (MRA).

(100) -The maximum number of replications or treatments allowed.

(500) -The maximum number of fragments allowed.

All other indices are explained in the glossary together with the appropriate array variable.

All variables beginning with the letter "U" are double precision and used in the random number generator. Only two of these variables are defined in the glossary. The remaining variables are best explained in the comments to the test listing in Appendix F and the referenced document specified there.

Throughout most of the glossary, range has been used in the description of the variables. Range (R) and Distance (DN) are the same when there is no crosswind. With crosswind, distance is equal to the square root of the sum of squares of range (R) and crossrange (XR).

-A-

AE (500)	Defines the lower limit of an elevation zone (deg) for each fragment
ALT	Altitude of the site where the munitions are located. A random variable. A constant when ALTMIN and ALTMAX are the same. (ft)
ALTMAX	Maximum altitude of sites being simulated. (ft)
ALTMIN	Minimum altitude of sites being simulated. (ft)
AM (500)	The average presented area to mass ratio for a fragment. (in.^{2}/lb)
AQ	An angle used to calculate the range and cross-range velocities after ricochet. (radians)
AR2 (500)	Defines the maximum to average presented area ratio for each fragment.
AS	Azimuth sector size. Describes the angular width of the hazard volume. See Figure 1 where AS= 10 deg.
AX	An angle in radians. Incorporates wind effects, if applicable, and is used to calculate the X (range) component of acceleration in the Runge-Kutta routine.
AY	An angle in radians. Used to calculate the Y (altitude) component of acceleration in the Runge-Kutta routine.
AZ	An angle in radians. Incorporates wind effects, if applicable, and is used to calculate the Z (cross-range) component of acceleration in the Runge-Kutta routine.

-B-

B	A constant used to convert degrees. to radians or radians to degrees.
BB	A constant equal to 2*PI. It is used in the generation of normal random numbers in BLOCK-8.
BQ	Soil constant used for ricochet calculations. A random variable between 0.5 and 4.0. A constant when SCMAX and SCMIN are the same.

-C-

CD	Fragment drag coefficient which is a function of Mach Number. The function is approximated by four straight lines. This is a random variable.
CH	High limit of uncertainty for the low subsonic (MN = 0.1) drag coefficient at a particular value of AR2 (500).
CKE	Computed kinetic energy of a fragment calculated within the hazard volume to determine whether the fragment is hazardous. (ft-lbs)
CL	Low limit of uncertainty for the low subsonic (MN = 0.1) drag coefficient at a particular value of AR2 (500).

CX	A flag having the value of 0 or 1. Used to determine the range increment where the fragment goes through the top plane of the hazard volume from below. This action occurs when CX equals 1 and CY equals 0.
CY	A flag having the value of 0 or 1. When equal to zero, the fragment is below the top plane of the hazard volume. When equal to 1, the fragment is above this plane.

-D-

D1	The drag coefficient for a particular fragment at a Mach Number of approximately 0.1. This a random variable. The drag coefficient lies between a Max (CH) and a Min (CL) value. This is the anchor point for constructing the four straight lines which approximate the drag curve as a function of Mach Number.
D2	Equals D1 + 0.2. This CD point at Mach Number 0.75 determines the first straight line drawn from D2 through D1 and then to the CD axis.
D3	Equals D1 + 0.65. This CD point at Mach Number 1.5 determines the second straight line drawn from D3 to D2.
D4	Equals D1 + 0.5. This CD point at Mach Number 2.5 determines the third straight line drawn from D4 to D3. The fourth straight line above Mach Number 2.5 has a constant CD value of D1 + 0.5.
D5 (97)	The 50th percentile value of hazardous density, for the number of units specified, for each 100-ft increment of range (Frags/ft^2)
D6H (100, 97)	Hazardous fragment density by replication or treatment for each 100-ft range increment for the number of units specified. (Frags/ft^2)
D7MIN (97)	The minimum hazard density for a given 100-ft range increment for the number of units specified. (Frags/ft^2)
D8MAX (97)	The maximum hazard density for a given 100-ft range increment for the number of units specified. (Frags/ft^2)
D9 (97)	The hazard density for the percentile level chosen for the number of units specified. (Frags/ft^2)
DC	Hazard density criterion. Currently one fragment per 600 ft^2 for personnel. For other targets use one divided by 100 times the presented area of the target.
DD	A value calculated and used in the generation of random normal numbers for defining a value of the magnitude of initial fragment velocity in the MONTE CARLO option.
DF	A range difference value used to calculate the range where the fragment pierces the hazard volume when the trajectory is in an upward direction. (ft) See BLOCK-17
DH (97)	The average hazard density for each 100-ft increment of range for the number units specified. (Frags/ft^2)
DI (7)	Seven variables for time, velocity and displacement used in the Runge-Kutta routine.
	DI (1) Elapsed time of flight. (s) (Not in basic Runge-Kutta calculations)

DI (2) The magnitude of the range (X component) of velocity. (ft/s)

DI (3) Range measured along the X component of displacement. (ft)

DI (4) The magnitude of the altitude (Y component) of velocity, positive upwards and negative downwards (ft/s).

DI (5) Altitude measured along the Y component of displacement, positive above ground level and negative below. (ft)

DI (6) The magnitude of the crossrange (Z component) of velocity. (ft/s)

DI (7) Crossrange measured along the Z component of displacement. (ft)

DLT — The time increment of integration in the Runge-Kutta routine. It is variable since it is based on a distance increment and the current velocity. (s)

DM — The depth measurement of the target. For an average male soldier, this dimension is 0.55 ft.

DN — The distance of fragment travel in the ground plane. Equal to the square root of the sum of squares of final range and crossrange. Distance equals range when there is no crossrange component. (ft)

DO (7) — Variables for velocity and acceleration used in the Runge-Kutta routine.

DO (1) Not used.

DO (2) Magnitude of the acceleration in the range (X component) direction. (ft/s^2)

DO (3) Magnitude of the velocity in the range (X component) direction (ft/s). Not currently used.

DO (4) Magnitude of the acceleration in the altitude (Y component) direction. (ft/s^2)

DO (5) Magnitude of the velocity in the altitude (Y component) direction (ft/s). Not currently used.

DO (6) Magnitude of the acceleration in the crossrange (Z component) direction (ft/s^2).

DO (7) Magnitude of the velocity in the crossrange (Z component) direction (ft/s). Not currently used.

DR — A constant for converting degrees to radians or radians to degrees.

DS (7) — A variable used to hold the values of velocity at increment start for the three component directions in the Runge-Kutta routine. Only indicies 2, 4, 6 are used. (ft/s)

DT (97) — Average total fragment density in each 100-ft range increment. Includes both hazardous and nonhazardous fragments for the number of units specified. ($Frags/ft^2$)

DW — The wind direction saved in degree notation for output.

DX	Running average of total fragment density at multiple points within one 100-ft range increment. (Frags/ft^2)

-E-

E	Elevation angle. Plus above the horizontal and minus below the horizontal. (radians)
EA	The angle of ricochet in the same plane as the incident angle. (radians)
EE	A value used in the generation of random normal numbers for use with the uncertainty of fragment initial velocity.
EQ (6)	The six equations for calculating ricochet angle as a function of incident angle for different soil constants. See BLOCK-19 and Appendix E.
ES	The size of the elevation angle zone calculated from the polar zone size. The size used currently is 10 deg. It depends on the size of polar zones used in the small-scale arena tests. The zone size determines the range of uncertainty in initial elevation angle. (deg)
EY	The absolute value of the incident angle used for ricochet calculations. (deg)
EZ	Flag which determines whether there is a cross-range component. Effects Runge-Kutta calculations.

-F-

F	An index and counter for numbering the fragments and controlling the fragment loop (BLOCK-7).
F1	A counter for specifying the Factor Level currently in use in the FULL FACTORIAL option. This counter pertains to the SOIL CONSTANT factor.
F2	A counter for specifying the Factor Level currently in use in the FULL FACTORIAL option. This counter pertains to the Height of Origin factor.
F3	A counter for specifying the Factor Level currently in use in the FULL FACTORIAL option. This counter pertains to the Elevation Angle factor.
F4	A counter for specifying the Factor Level currently in use in the FULL FACTORIAL option. This counter pertains to the Initial Velocity factor.
F5	A counter for specifying the Factor Level currently in use in the FULL FACTORIAL option. This counter pertains to the site Altitude factor.
F7	A counter for specifying the Factor Level currently in use in the FULL FACTORIAL option. This counter pertains to the Wind Speed factor.
FG	A constant used in calculating the kinetic energy of a fragment. It is equal to the fragment weight in grains divided by (2*7000*G). (lb-s^2/ft)
FHP (97)	Running weighted average hazard probability of hit for the number of units specified and, in turn, for each of the four range increments (100, 200, 300, and 400 ft) in the output.

FL (10, 25)	Factor Level for use in the FULL FACTORIAL option. The first index identifies the factor. The second index identifies the current level in use for a particular treatment.
FTP (97)	Running weighted average probability of hit including hazardous and nonhazardous fragments for the number of units specified and, in turn, for each of the four range increments (100, 200, 300, and 400 ft) in the output.
FW (500)	Fragment weight for each fragment. (grains)

-G-

G	Acceleration due to gravity. (ft/s^2)
GX	Running average of the number of hazardous fragments in a particular 100-ft range increment. It is possible to have a fragment hazardous at one point in the 100-ft increment and to be nonhazardous at a later point in the same increment.

-H-

H9 (10)	A character array variable which contains the names of the factors in the FULL FACTORIAL option.
HD (97)	Running weighted average hazardous density for the number of units specified. Applies to 100, 200, 300, and 400 ft range increments used in the output tables. (Frags/ft^2)
HM	Height measurement of the target. For an average male soldier this dimension is 5.72 ft.
HN (97)	Accumulated average hazardous number of fragments. Applies to 100, 200, 300, and 400 ft range increments used in the output tables.
HO	Height above the ground at which a fragment is ejected from the ammo stack. (ft)
HP (97)	Probability of hitting the target with hazardous fragments for each 100-ft range increment. The value is averaged over all replications or treatments.
HS	Height of the ammo stack above the ground. (ft)
HX	Running average of the hazardous density for the number of units specified. The average is for the points occurring in a particular 100-ft range increment. (Frags/ft^2)

-I-

I	Loop index. Used more than once when there is no conflict between loops.
IE (500)	Lower limit of the fragment elevation zone. (deg)
INTSTP	Subroutine for defining the Runge-Kutta displacement integration step.
IV (500)	Average magnitude of the fragment initial velocity vector. (ft/s)

-J-

J	Loop index. Used more than once where there is no conflict between loops.

-K-

K	Loop index. Used more than once where there is no conflict between loops.
K1	Constant used in the exponent of the Mach Number equation. (ft/s)
K3	Air density at sea level divided by 2. Division by 2 accounts for the factor 1/2 in the drag equation. (lb/ft^3)
K4	Constant used in the exponent of the air density equation. (ft)
K5	Constant (144) used to convert the average presented area of the fragment from square inches to square feet.
K9	Constant used to convert fragment weight in grains to pound-mass units for use in the kinetic energy hazard criterion calculations.
KE	Hazard kinetic energy criterion. (ft-lbs)
KK	Acceleration along the fragment velocity vector due to air drag. (ft/s^2)
KM	Constant (0.5 or 1) used as coefficients for the Runge-Kutta intermediate velocities.
KW	Weighting factor used when combining 100-ft increments into larger increments in the output tables. The weighting factor is equal to the mid-range of each 100-ft increment in hundreds of ft.

-L-

LE	The absolute value of the elevation angle at the end of each Runge-Kutta integration step (radians)

-M-

M1	Subsonic Mach Number pivot point used in constructing the straight line approximations to the drag curve. Currently equal to 0.75.
M2	Transonic Mach Number pivot point used in constructing the straight line approximations to the drag curve. Currently equal to 1.5.
M3	Supersonic Mach Number pivot point used in constructing the straight line approximations to the drag curve. Currently equal to 2.5.

MA — The presented area of the target in the plane perpendicular to the fragment trajectory. (ft^2)

MN — Mach Number

MR — Maximum computation range in ft or hundreds of ft depending on the computation involved.

MRA — Maximum computation range best specified in 1200 ft multiples. (ft)

-N-

N1 — A generated random normal number.

N2 — A second generated random normal number. The random normal number generator is constructed such that two numbers are generated in each pass. This variable is not currently used.

N4 — The number of interaction areas or units on the face of the stack towards the target area.

N8MIN (97) — Minimum number of final impacts for each 100-ft range increment for the specified number of units.

N9MAX (97) — Maximum number of final impacts for each 100-ft range increment for the specified number of units.

NAM — Character variable containing the code name for the output device. For the FRAGHAZ program the code (LPT1) designates the Epson Printer with the IBM PC-AT.

NF — The number of fragments used in the simulation. A separate trajectory is calculated for each fragment, for each replication or treatment.

NH (97) — Average number of hazardous fragments for each 100-ft range increment for the number of units specified.

NL (10) — The number of levels for each factor in the FULL FACTORIAL option. Index identifies which factor.

NP — The number of replications or treatments for which the initial and final conditions of each fragment trajectory will be printed.

NP2 (4, 97) — The number of units required to just exceed the Probability of Hit criterion for each 100-ft range increment. There are four values in the output: minimum, maximum, 50th percentile, and the specified percentile. Values pertain to 100, 200, 300, and 400 ft range increments.

NT (97) — Equally weighted total number of fragments (hazardous and nonhazardous) for each 100-ft range increment for the specified number of units. The average is accumulated after each replication or treatment and stored in the variable TN (97).

NR	Number of replications selected for the MONTE CARLO option. Number of treatments is computed internally for the FULL FACTORIAL option and also stored in this variable
NX	The number of fragments associated with a trajectory for the specified number of units.

-O-

There are no variables beginning with "O".

-P-

P	A counter which specifies the number of trajectory points in any one 100-ft range increment of the hazard volume. It is used to keep running averages of density and probability of hit within the given 100-ft increment.
P5	Designates the 50th percentile elements in the sorted lists of hazardous density and probability of not hitting the target.
P9	Designates the specified percentile elements in the sorted lists of hazardous density and probability of not hitting the target. The 90th percentile is currently specified for hazard curves.
PA	Upper angle of the polar zone containing a particular fragment. (deg)
PC	Probability of hit hazard criterion currently equal to 0.01.
PCT	The percentile level selected at the outset. (percent)
PCTD	The selected percentile level as a decimal for use in calculations.
PH (97)	Average probability of not hitting the target with hazardous fragments for each 100-ft increment for the specified number of units. A running average is kept for each replication or treatment and stored in the variable HP (97).
PI	The circular constant equal to 3.141593.
PT (97)	Average probability of not hitting the target with hazardous and nonhazardous fragments for each 100-ft range increment for the specified number of units. An accumulating average is kept for each replication or treatment and stored in the variable TP (97).
PX (100, 97)	The probability of not hitting the target with hazardous fragments for one unit (interaction area) and for each replication or treatment and each 100-ft range increment.
PW	Constant for calculating the presented area of the top of a 100-ft segment of the hazard volume with an angular width equal to the variable (AS).

-Q-

Q	Character variable which contains the DISK file name for all the frag data.
QE	Ricochet angle ratio of reflected to incident angle.
QV	Ricochet velocity ratio of reflected to incident velocity.

-R-

R	Index for range loops expressed in hundreds of feet.
RB	Number of rebounds for a ricocheting fragment.
RI	Range increment for the four sets of output tables. RI has values of 100, 200, 300, and 400 ft.
R12	Equals RI in hundreds of ft.
RL	Last range as an integer in hundreds of feet to determine if a fragment has passed from one 100-ft increment to the next in the hazard volume.
RN	Range of fragment. Component of distance along X axis. (ft)
RND (UIX)	Function for calculating uniform random numbers between 0 and 1 for the MONTE CARLO option.
RO	One-half the air density. (lb/ft^3). The one-half factor is applied here to save including it in each drag-deceleration equation.
RZ	A flag to indicate whether the program will be run under the MONTE CARLO or FULL FACTORIAL option. RZ = 1 for MONTE CARLO and 0 for FULL FACTORIAL..

-S-

S1	Variable used in calculating the running average of total fragment density (hazardous and nonhazardous) within a single 100-ft range increment for the number of units specified. (Frags/ft^2)
S2	Like S1 but used with total (hazardous and nonhazardous fragments) probability of not hitting the target for the number of units specified.
S3	Like S1 but used with hazardous density for the number of units specified. (Frags/ft^2)
S4	Like S1 but used with hazardous probability of not hitting the target for the specified number of units.
S5	Like S1 but used with hazardous probability of not hitting the target for one unit.

S6	Like S1 but used with hazardous number of fragments for the specified number of units.
SCMAX	Maximum Soil Constant (SCMIN to 4.0)
SCMIN	Minimum Soil Constant (0.5 to 4.0)
SIGS	Stack Inert Ground Standoff (ft). Distance from ground to the beginning of fragmenting cases on the face of the stack towards the target area. For a typical wooden pallet, SIGS would be about 0.5 ft.
SUM	Used when weighting 100-ft range increments for combining into 200, 300, and 400 ft range increments. It is the sum of the weightings for each 100-ft range increment used as a divisor to obtain the weighted average.

-T-

T	An index and counter used for designating the Replication or Treatment number.
T5	A switching variable used in the SORT routines.
T8MIN (97)	Accumulated minimum number of final impacts in each 100-ft range increment for the specified number of units for the 100, 200, 300, and 400 ft output range increments.
T9MAX (97)	Accumulated maximum number of final impacts in each 100-ft range increment for the specified number of units for the 100, 200, 300, and 400 ft output range increments.
TA	Total presented area, perpendicular to the fragment trajectory, of a 100-ft increment of the hazard volume (ft^2).
TD (97)	Running weighted average total density (hazardous and nonhazardous fragments) for each 100-ft range increment. ($Frags/ft^2$)
TI (97)	Accumulated average number of final impacts in each 100-ft range increment for the specified number of units for the 100, 200, 300, and 400 ft output range increments.
TJ	Accumulates the number of trajectories with range greater than the maximum computation range specified at the outset in variable MRA. The number is the total for all replications or treatments.
TN (97)	Average total number of fragments (hazardous and nonhazardous) for each 100-ft range increment for the specified number of units.
TP (97)	Accumulated average probability of hitting the target in each 100-ft range increment for the specified number of units.
TS	Character variable. Contains a title or description of the target.

-U-

UDUM A dummy variable for accessing the RND(UIX) function.

USE Double precision integer seed for the random number generator used with the MONTE CARLO option. (1 - 2147483646)

-V-

V Magnitude of the fragment velocity vector. Sum of its X, Y, and Z components. (ft/s)

VA Magnitude of the fragment velocity vector after ricochet in the same plane as the incident velocity vector. (ft/s)

VF Magnitude of the fragment velocity vector at final impact. (ft/s)

VP Magnitude of the fragment velocity vector, with wind effects added. Sum of the X, Y, and Z component speeds with wind added. (ft/s)

VQ (6) Ratio of the magnitudes of the velocity vector before and after ricochet for six different values of soil constant.

VR Incident magnitude of the fragment velocity vector used for ricochet calculations. Sum of the X, Y, and Z component speeds. (ft/s)

VS Speed of sound at sea level equal to 1116.4 ft/s.

VXP Magnitude of the X component of the fragment velocity vector (VP). Contains the effects of wind. (ft/s)

VYP Magnitude of the Y component of the fragment velocity vector (VP). Contains the effects of wind. (ft/s)

VZP Magnitude of the Z component of the fragment velocity vector (VP). Contains the effects of wind. (ft/s)

-W-

WD Wind direction (deg) measured clockwise from the X-Y plane. Tail wind is 0 deg.

WM Width measurement of the target. For an average male soldier this dimension is 1.00 ft.

WS Magnitude of the wind velocity vector. Can be different for each replication or treatment if WSMAX and WSMIN are different. If WSMIN and WSMAX are the same then wind speed is constant for all replications or treatments. (ft/s)

WSMAX Maximum magnitude of the wind velocity vector. (ft/s)

WSMIN Minimum magnitude of the wind velocity vector. (ft/s)

-X-

X5	The number of fragment multipliers. See Appendix D for explanation of fragment multipliers.
X5D(97)	Weighted average of the 50th percentile hazardous density for each 100, 200, 300, and 400 ft range increment, for the specified number of units (Frags/ft^2)
X5P(97)	Weighted average of the 50th percentile hazardous probability of hit for each 100, 200, 300, and 400 ft range increment, for the specified number of units.
X7DMIN (97)	Minimum hazard density for each 100, 200, 300, or 400 ft range increment, for the specified number of units, for all replications or treatments. (Frags/ft^2)
X8DMAX (97)	Maximum hazard density for each 100, 200, 300, or 400 ft range increment, for the specified number of units for all replications or treatments. (Frags/ft^2)
X9D (97)	Hazard density for the percentile specified, for each 100, 200, 300, or 400 ft range increment, for the specified number of units for all replications or treatments. (Frags/ft^2)
X7PMIN (97)	Minimum hazard probability of hit for each 100, 200, 300, or 400 ft increment, for the specified number of units, for all replications or treatments.
X8PMAX (97)	Maximum hazard probability of hit for each 100, 200, 300, or 400 ft increment, for the specified number of units, for all replications or treatments.
X9P (97)	Hazard probability of hit for the percentile specified, for each 100, 200, 300, and 400 ft increment, for the specified number of units, for all replications or treatments.
XA	Cross-range angle for final impact; equal to the arctan of crossrange divided by range. (deg)
XD	Displacement increment of integration in the Runge-Kutta routine selected at the beginning of the trajectory and after each ricochet. (ft)
XE	Elevation angle in degrees used when going to the Integration Step Subroutine initially and after each ricochet. (deg)
XK (4, 7)	The four K constants in the 4th order Runge-Kutta routine. For the second index, only 2, 4, 6 are used to calculate X, Y, and Z components of velocity. (ft/s)
XL	Flag to determine whether cross-range calculations will be made in the Runge-Kutta routine. XL = 4 for no cross-range calculations and XL = 6 for cross-range calculations. Cross-range calculations are only made when there is a cross-range component of wind.
XN (97)	Equally weighted average number of final impacts for each 100, 200, 300, and 400 ft range increment, for the specified number of units, averaged over all replications or treatments.

XP	Total (hazardous and nonhazardous fragments) probability of not hitting the target averaged over the number of points within a single 100-ft range increment.
XR	Cross-range displacement of fragment. (ft)
XV	Initial magnitude of the velocity vector retained for the output trajectories tables. (ft/s)

-Y-

Y2 (36)	Fragment multiplier. The index indicates the upper bound of the 5 or 10 deg polar zones containing a specific fragment. For example, Y2 (4) for 10 deg polar zones would indicate polar zone 30 to 40 deg.
Y5D(97)	The number of units required to just exceed the hazard density criterion for each 100, 200, 300, and 400 ft range increment, for 50th percentile values.
Y7DMIN (97)	Minimum number of units needed to just exceed the hazard density criterion for each 100, 200, 300, and 400 ft range increment.
Y8DMAX (97)	Maximum number of units needed to just exceed the hazard density criterion for each 100, 200, 300, and 400 ft range increment.
Y9D (97)	The number of units required to just exceed the hazard density criterion for each 100, 200, 300, and 400 ft range increment for the percentile specified.
Y	Used to draw the first random number from the seed. This starts the random number sequence for the MONTE CARLO option. This first number is not used.
YE	Initial elevation angle in degrees saved for output trajectories tables. (deg)
YN (100, 97)	Number of fragments (hazardous and nonhazardous) with final impacts in each 100-ft range increment, for each replication or treatment, for the number of units specified.

-Z-

Z5P(97)	Weighted average of the 50th percentile hazardous probability of hit for a single unit, for each 100, 200, 300, and 400 ft range increment.
Z7PMIN (97)	Weighted average of the minimum probability of hit for a single unit, for each 100, 200, 300, and 400 ft range increment.
Z8PMAX (97)	Weighted average of the maximum probability of hit for a single unit, for each 100, 200, 300, and 400 ft range increment.
Z9P (97)	Weighted average of the probability of hit for a single unit for each 100, 200, 300, and 400 ft increment for the percentile specified.

ZP	Running average of probability of not hitting the target for each point within a single 100-ft range increment, for the number of units specified.
ZZP	Running average of probability of not hitting the target for each point within a single 100-ft range increment, for a single unit.

APPENDIX D

FRAGMENT MULTIPLIERS

INTRODUCTION

In order to make the program applicable to any size ammo stack with any number of interaction areas or units on the face of the stack towards the target area, it is necessary to have effective number of fragments in unit values. The two unit values required are one interaction area (unit) and one deg of azimuth. In the small-scale fragmentation arena test there is almost always more than one interaction area and more than one deg of azimuth recovery.

Three procedures used to recover fragments and calculate fragment multipliers are shown in Figures D-1, D-2, and D-3.

RECOVERY BY POLAR ZONE ONLY

This procedure is the least accurate in locating the position of a fragment in terms of polar and azimuthal angles. The marking of the fragment recovery packs is shown in Figure D-1. To calculate fragment multipliers for each 10 deg polar zone, use is made of Fragmentation Arena Multipliers.[D-1]

The Fragment Arena Multiplier is the ratio of the area of the 360 deg polar zone to the partial area of the polar zone which is projected onto the recovery packs. The fragment multiplier is then calculated as follows for one interaction area (unit) and one-deg of azimuth.

$$M_F = \frac{M_A}{(360)(N)}$$

where

M_F - Fragment multiplier for one interaction area (unit) and one deg of azimuth for the particular polar zone in question.

M_A - Fragmentation Arena Multiplier for the particular polar zone in question.

N - Number of interaction areas (units) on the face of the stack towards the recovery packs for the small-scale arena test.

[D-1] McCleskey, Frank, *Fragmentation Arena Multipliers*, Naval Surface Weapons Center report NSWC TN 84-43, March 1984.

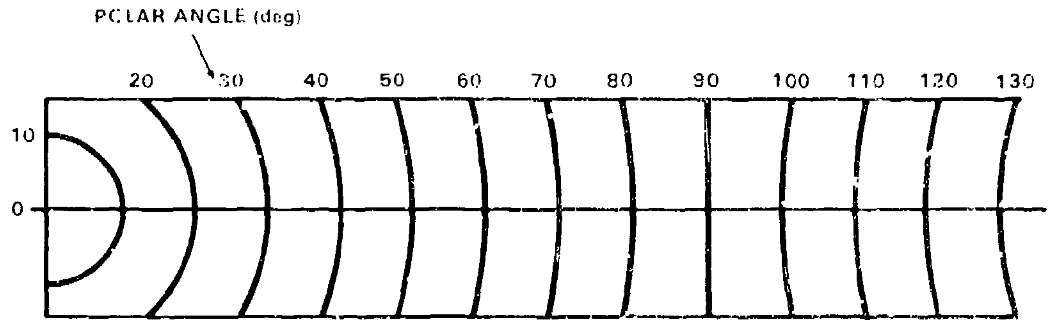


FIGURE D-1. RECOVERY BY POLAR ZONE ONLY

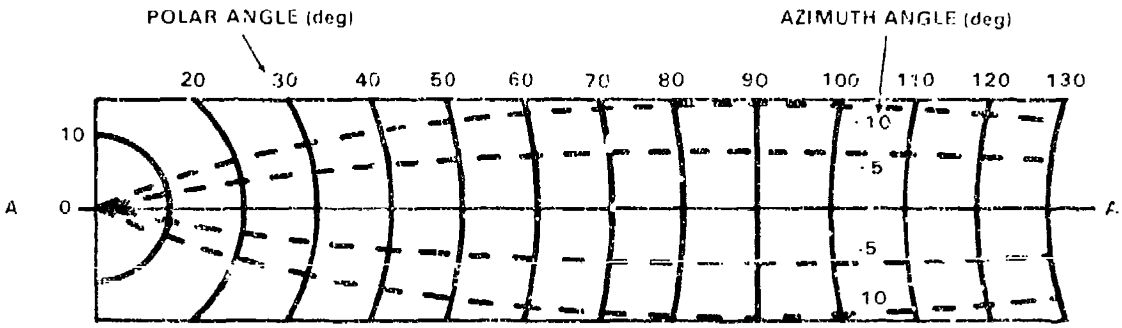


FIGURE D-2. RECOVERY BY POLAR AND AZIMUTHAL ZONES

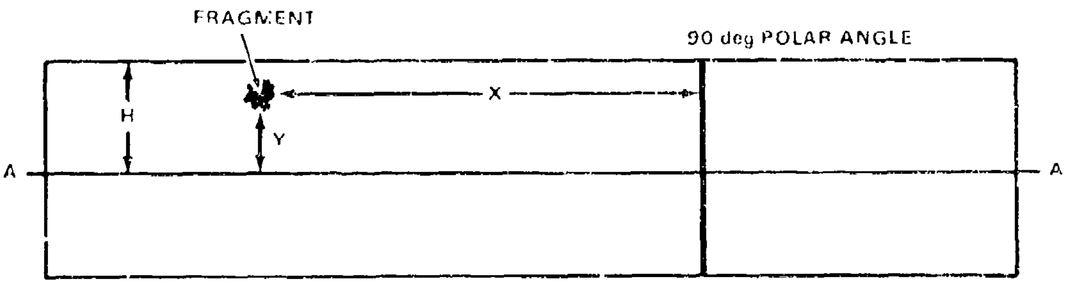


FIGURE D-3. RECOVERY BY X-Y COORDINATES

RECOVERY BY POLAR AND AZIMUTHAL ZONES

Figure D-2 shows recovery pack marking for both polar and azimuthal zones. This method decreases the uncertainty in azimuthal coverage but presents a problem in identifying the most dense region of fragmentation in azimuthal terms. In the field, it is difficult to perceive the overall fragment distribution due to the large dimensions of the recovery packs. More azimuthal lines may be required. In any event, once the azimuthal extent of the most dense fragmentation is selected, the fragmentation multipliers for each polar zone are calculated as follows:

$$M_F = \frac{1}{NA_s}$$

where

M_F - Fragmentation multiplier for one interaction area (unit) and one degree of azimuth for the particular polar zone in question. If the azimuth sector is the same for all polar zones then the fragment multipliers for all polar zones will be the same.

N - Number of interaction areas (units) on the face of the stack towards the recovery packs for the small-scale arena test.

A_s - Size of the azimuth sector enclosing the area of high fragment density for each polar zone (degrees).

RECOVERY BY X-Y COORDINATES

This procedure is the most flexible and most accurate of the three procedures in locating fragment position. The X coordinate is measured from the 90 deg polar angle trace on the recovery packs. This trace is a straight vertical line. Symmetry exists right and left of the 90 deg polar trace as shown in Figures D-1 and D-2. The Y dimension is measured from the longitudinal center line of the packs (A-A). Again, there is symmetry above and below the center line (A-A). All fragments have a specified minimum weight (currently 300 grains). The X-Y positions for all fragments recovered from the packs are plotted on a piece of graph paper. The length of the graph rectangle will be about ($130\pi R/180$) where R is the radius of the arena. The range of polar angles is from 0 to 130 which is consistent with ricochet limits. Polar and azimuthal lines are then drawn on the graph paper and the azimuthal limits are selected so as to bound the area of highest fragment density. Generally, the azimuthal bounds should cover about 10 deg to be consistent with the azimuthal angle of the hazard volume (Figure 1 in the GENERAL PROGRAM DESCRIPTION Section of the main body). These angles can be changed to meet special conditions. Should they need to be changed, the user must also change the elevation (polar) zone size (ES) and the azimuthal coverage size (AS) in BLOCK 1 (Variable Constants) of the program listing in Appendix B.

The following method can be used to superimpose polar and azimuthal traces on graph paper:

Given: R - Arena radius (ft)

θ - Any polar angle converted to radians

H - Height of recovery packs above or below the center line (A-A) (ft)

$$\beta = tan^{-1}\left(\frac{H}{R}\right)$$

Increment Y from 0 to H STEP 0.5 when $\beta < \theta$

Increment Y from 0 to R tan θ STEP R tan $\theta/10$ when $\beta \geq \theta$

then

$$\lambda = tan^{-1}\left(\frac{Y}{R}\right)$$

$$\psi = sin^{-1}\left(\frac{sin\,\lambda}{sin\,\theta}\right)$$

$$\phi = tan^{-1}(tan\,\theta\,cos\,\psi)$$

$$X = R\left(\frac{\pi}{2} - \phi\right)$$

Plot each of the X-Y coordinates and draw a smooth curve through them. When all the polar angle traces are plotted, the azimuthal traces can be plotted by finding the Y dimension where the azimuthal trace intersects each of the polar angle traces. The Y dimension is found as follows:

Given: R - Arena radius (ft)

θ - Any polar angle converted to radians

α - Any azimuthal angle converted to radians

then

$\mu = \sin^{-1} (\sin\theta \sin\alpha)$

$Y = R \tan\mu$

Plot each of the intersection points and draw a smooth curve through them. Remember that symmetry exists right and left of the 90 deg polar trace, and above and below the longitudinal center line (A-A) of the recovery packs.

By observation select the azimuthal bounds which best enclose the area of high fragment density. The fragment multipliers are then calculated as follows

$$M_F = \frac{1}{NA_S}$$

where

M_F - Fragmentation multiplier for one interaction area (unit) and one deg of azimuth for the particular polar zone in question. If the azimuth sector is the same for all polar zones then the fragment multipliers for all polar zones will be the same.

N - Number of interaction areas (units) on the face of the stack towards the recovery packs for the small-scale arena test.

A_S - Size of the azimuth sector enclosing the area of high fragment densities for each polar zone (degrees)

SAMPLE CALCULATION

Suppose one wanted to find the fragment multiplier for all fragments in a particular polar zone (θ_1 - θ_2) which is bounded by an 11 deg azimuthal sector. Further assume that there were six interactions areas (units) facing the recovery packs in the small-scale arena test. Then the fragment multiplier would be

$$M_{F(\theta_1-\theta_2)} = \frac{1}{6 x 11} \approx 0.01515$$

In the computer program, when one needs to calculate the trajectory and hazards for any fragment in this polar zone, one would associate an effective number of fragments with the trajectory. Suppose the stack one was simulating in the computer program had 46 interaction areas (units) facing the target area and one was using a 10 deg azimuthal width for the hazard volume. The effective number of fragments to be associated with each fragment in the particular polar zone would be:

$$N_E = 0.01515 \times 46 \times 10 = 6.969$$

This effective number of fragments would be used to calculate hazard density, hazard probability of hit, and number of final impacts for the particular fragment trajectory.

This procedure assumes linear scaling. For example if there were four units in the small-scale test and one was simulating 40 units in the full-scale simulation in the computer program, then for each fragment recovered in the small-scale test within polar and azimuthal bounds, one would assume 10 identical fragments for the full-scale simulation. Only one trajectory would be calculated but one would associate 10 identical fragments with it for calculation of density, probability of hit, and number of final impacts. For azimuthal coverage one would assume constant density throughout the azimuthal sector for the polar zone in question.

APPENDIX E

RICOCHET DATA

All ricochet data are taken from a report published in 1970.[E-1] The data permit fragment ricochet angle and velocity to be calculated from the incident angle and velocity for a given soil type.

Table E-1 gives all the data necessary to compute ricochet angle and velocity.

TABLE E-1. FRAGMENT RICOCHET DATA

Soil Constant	Critical Angle (Deg)	Angle and Velocity Ratio Equations
0.25	6.25	$V'/V = -0.01597\,E^2 + 0.02156\,E + 0.9617$
		$E'/E = 0.13829\,E^2 - 0.98645\,E + 2.8155$
0.50		$V'/V = -0.00861\,E^2 + 0.00692\,E + 0.96302$
		$E'/E = 0.08549\,E^2 - 0.78423\,E + 2.9012$
1.0		$V'/V = -0.00387\,E^2 - 0.00414\,E + 0.95592$
		$E'/E = 0.07515\,E^2 - 0.73919\,E + 3.1056$
2.0	14.0	$V'/V = -0.00342\,E^2 - 0.00097\,E + 0.9409$
		$E'/E = 0.02142\,E^2 - 0.37397\,E + 2.7858$
3.0		$V'/V = -0.00243\,E^2 - 0.0052\,E + 0.9308$
		$E'/E = 0.01707\,E^2 - 0.32521\,E + 2.8092$
4.0	17.0	$V'/V = -0.00188\,E^2 - 0.00821\,E + 0.93802$
		$E'/E = 0.01369\,E^2 - 0.2958\,E + 2.8262$

where

V' - Ricochet Velocity

V - Incident Velocity

E' - Ricochet Angle

E - Incident Angle

The critical angle is the incident angle above which the fragment will not ricochet. An approximate equation relating soil constant to critical angle is:

$$E_c \doteq 10.8\,(BQ)^{.38}$$

[E-1] Reches, M., *Fragment Ricochet off Homogenious Soils and Its Effects on Weapon Lethality* (U), Army Material Systems Analysis Agency Technical Memorandum No. 79, August 1970 (CONFIDENTIAL).

where

E_c - Critical angle (Degrees)

BQ - Soil constant

The soil constant for various soils is shown in Figure E-1. Subsequent to the publication of the ricochet report it has been common practice to limit the minimum soil constant to 0.5.

In the experiments conducted for the ricochet report, incident velocities varied between 1000 and 5000 ft/s. It was found that the critical angle and the ratios for velocity and angle were relatively insensitive to incident velocity. In the FRAGHAZ program, the critical angle and ricochet ratios are further assumed to be applicable to incident velocities as low as 20 ft/s and as high as 10000 ft/s. Although this assumption is not supported by tests, it does appear reasonable in light of the good agreement obtained with FRAGHAZ predictions of the range distributions of fragments and actual fragment pickup from large-scale tests (see Figures 5 and 6 in the GENERAL PROGRAM DESCRIPTION Section of the main body).

In the ricochet experiments, slender rods with a square cross section were used. These rods had flat faces and the length to width to thickness ratios were 3:1:1 in most cases. The author of the ricochet report has stated that these rods are reasonable substitutes for irregular fragments. Again, the results given in Figures 5 and 6 lend strength to this supposition.

In application, when the soil constant is between the discrete values given in Table E-1 resort is made to linear interpolation for the angle and velocity ratios.

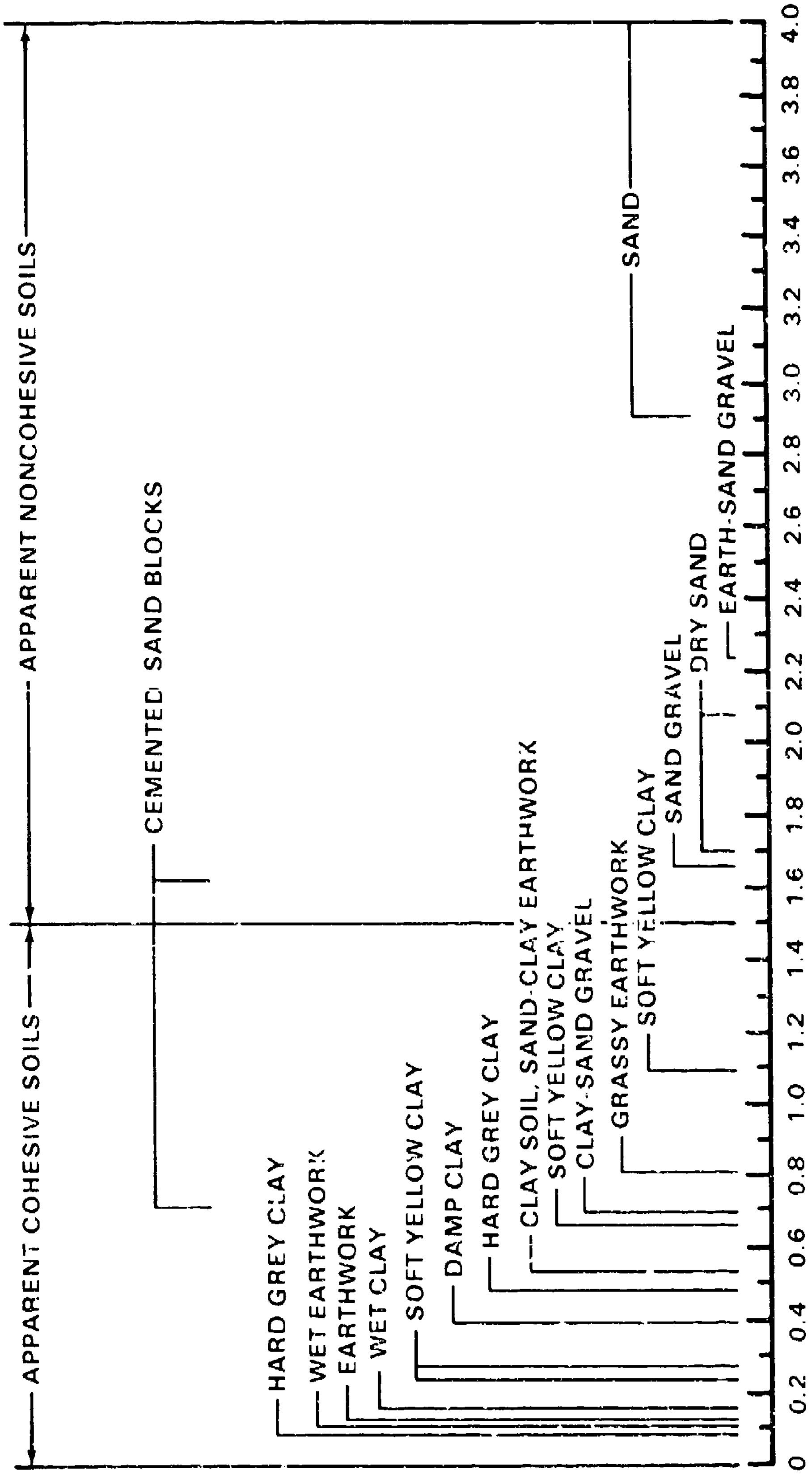


FIGURE E-1. SOIL CONSTANTS FOR VARIOUS SOILS

APPENDIX F

PORTABILITY TEST FOR THE RANDOM NUMBER GENERATOR

INTRODUCTION

There are situations in which it is desirable to have a random number generator that is machine independent. In the case of FRAGHAZ it is desirable that the user be able to check the MONTE CARLO aspects of the program with a test case. In order to do this, the user must be able to generate the same sequence of random numbers that was used in generating the test case. This requires a portable random number generator. One such portable generator (used in FRAGHAZ) has been described in the literature.[F-1] The user must first assure himself that the portable generator is indeed portable on his computer. A suitable test is described below.

PORTABILITY TEST

The generator presented in Listing F-1 is applicable to most any computer having a double precision option which can represent integers from 0 to 2^{31}-1. This is usually the case even with older eight-bit microcomputers. This generator is a full cycle type which will produce a sequence of random numbers between 1 and 2^{31} - 2 without recycling; that is, more than 2 billion numbers without recycling. The generator and its variables are described in the reference. To date, this generator has been tested successfully on the following six computers:

CONTROL DATA CDC 865
DIGITAL VAX 785
IBM - AT
APPLE II e
APPLE MACINTOSH
TANDY TRS-80, MOD 1, LEVEL II

In each case the checks were exact. Both BASIC and FORTRAN languages were used.

To check portability, the user should type in the program given in Listing F-1.

If the user's computer has an integer word size of at least 2^{31} - 1, he may want to use the INTEGER procedure presented in the Schrage reference. Given the same seed, the INTEGER procedure will generate the same sequence of random numbers as the DOUBLE PRECISION procedure given in Listing F-1. The INTEGER procedure will run 4 or 5 times faster.

Using seeds zero or 2147483647 will produce a sequence of random numbers all equal to zero. This may be useful in special cases. Using these seeds will require two changes in the program listing given in Listing B-1 of Appendix B. First, delete line 985. Second, change line 400 to read:

```
400 DD = SQRT (-2. * LOG(RND(UDUM + 1E-06)))
```

F-1 Schrage, Linus, *A More Portable Fortran Random Number Generator*, ACM Transactions on Mathematical Software, Vol 5, No. 2, June 1979, pp. 132-138.

LISTING F-1. RANDOM NUMBER PORTABILITY CHECK

```
      REAL JRN
      DOUBLE PRECISION DRAND,UIX,UANS
      UIX = 1.D0
      UANS = DRAND(UIX)
      DO 1000 I = 2,1005
         UANS = DRAND(UIX)
         JRN = INT(UANS * 1.D06) / 1.D06
         IF(I .GT. 995) WRITE(*,*)I,UIX,UANS,JRN
 1000 CONTINUE
      STOP
      END

      DOUBLE PRECISION FUNCTION DRAND(UIX)
C  PORTABLE RANDOM NUMBER GENERATOR USING THE RECURSION:
C  UIX = UIX * UA MOD UP
      DOUBLE PRECISION UA,UP,UIX,UB15,UB16,UXHI,UXALO,ULEFTLO,UFHI,UK
      DATA UA/16807.D0/,UB15/32768.D0/,UB16/65536.D0/,UP/2147483647.D0/
C  GET 15 HI ORDER BITS OF UIX
      UXHI = UIX / UB16
      UXHI = UXHI - DMOD(UXHI,1.D0)
C  GET 16 LO BITS OF UIX AND FORM LO PRODUCT
      UXALO = (UIX - UXHI * UB16) * UA
C  GET 15 HI ORDER BITS OF LO PRODUCT
      ULEFTLO = UXALO / UB16
      ULEFTLO = ULEFTLO - DMOD(ULEFTLO,1.D0)
C  FORM THE 31 HIGHEST BITS OF FULL PRODUCT
      UFHI = UXHI * UA + ULEFTLO
C  GET OVERFLO PAST 31ST BIT OF FULL PRODUCT
      UK = UFHI / UB15
      UK = UK - DMOD(UK,1.D0)
C  ASSEMBLE ALL THE PARTS AND PRESUBTRACT UP
C  THE PARENTHESIS ARE ESSENTIAL
      UIX = (((UXALO-ULEFTLO*UB16) - UP) + (UFHI-UK*UB15) * UB16) + UK
C  ADD UP BACK IN IF NECESSARY
      IF(UIX .LT. 0.D0) UIX = UIX+UP
C  MULTIPLY BY 1/(2**31-1)
      DRAND = UIX * 4.656612875D-10
      RETURN
      END
```

The seed UIX = 1.0 is in Double Precision. The DO Loop goes from 2 to 1005 and prints out results for draws 996 thru 1005. The loop starts with two to be compatible with the reference which seems to have counted the seed as the first draw. The 1000th draw results are the ones given in the reference. The results should be identical to those given in Table F-1. The table has four columns. The first is the number of the random number drawn. The second is the double precision random number as an integer. The third is the random number as a double precision decimal fraction between 0 and 1. The fourth is a single precision random number (JRN) between 0 and 1 having six significant digits. This single precision number is the one used in FRAGHAZ for all random variables.

If the user cannot meet the portability check then he will be unable to directly verify the test case for the MONTE CARLO option. Hand cases will be required with a random number generator chosen by the user. The FULL FACTORIAL test case does check everything but paths unique to the MONTE CARLO option and crosswind effects which have not been used in practical problems to date.

TABLE F-1. RANDOM NUMBER PORTABILITY CHECK

996	1.1509574630000E+009	5.3595633407831E-001	5.359560E-001
997	1.7568721120000E+009	8.1810732964676E-001	8.181070E-001
998	1.9969237810000E+009	9.2989009889983E-001	9.298900E-001
999	1.4235519510000E+009	6.6289303432580E-001	6.628930E-001
1000	5.2232923000000E+008	2.4322850174068E-001	2.432280E-001
1001	2.0217033210000E+009	9.4142897139989E-001	9.414280E-001
1002	1.2814532130000E+009	5.9672315303659E-001	5.967230E-001
1003	2.7065512800000E+008	1.2603361537296E-001	1.260330E-001
1004	5.3037195000000E+008	2.4697368509089E-001	2.469730E-001
1005	1.9042286000000E+009	8.8672554157032E-001	8.867250E-001

```
Stop - Program terminated.
```

APPENDIX G

WEIGHTING FACTORS

In addition to the intermediate output of initial and final conditions for individual trajectories, the final output consists of statistics for three basic values: number of fragments, fragment density, and fragment probability of hit. In the FRAGHAZ program all statistics are calculated on the basis of 100-ft range increments within the hazard volume. In the past, it has been helpful to combine these statistics for 100-ft increments into larger increments of 200, 300, and 400 ft. This was done to smooth data for final hazard curves. Since the establishment of procedures to retain and eliminate points for final hazard curves explained in the GENERAL PROGRAM DESCRIPTION Section of the main body, the need for larger combined increments has diminished. It is considered useful, however, to retain combined increments for the wide variety of possible problems for which the program is intended.

When combining 100-ft increments for number of fragment final impacts, no weighting factors are needed. Simple addition is all that is required. For combining 100-ft increments with respect to the number of fragments passing through increments, a simple unweighted average is appropriate. When combining 100-ft increments for fragment density and probability of hit, however, weighting factors are necessary to account for the divergent nature of the pie-shaped hazard volume, Figure G-1. Both density and probability of hit depend on the presented area of the 100-ft increments which increase with range.

There are a number of ways to derive weighting factors to account for the divergent nature of the hazard volume. The procedure to be used here will be based on the volumes of the individual 100-ft increments; that is, the weighting factor for a particular 100-ft increment will be proportional to its volume. This is consistent with the presented area aspects of density and probability of hit calculations because the height of the hazard volume is constant for all increments.

Figure G-1 shows three 100-ft increments which are to be combined into one 300 ft increment for density or probability of hit purposes. All range values will be in hundreds of feet which does not reduce the generality of the procedure. Starting with the first 100-ft increment (R_1, to R_2), the volume is:

$$V_1 = \frac{\pi A}{360}(R_2^2 - R_1^2)H$$

where

V_1 = Volume of the 100-ft increment R_1 to R_2.

A = Constant azimuthal width of the hazard volume in degrees. (See Figure G-1)

R_2 = Maximum range of the 100-ft increment in hundreds of feet.

R_1 = Minimum range of the 100-ft increment in hundreds of feet.

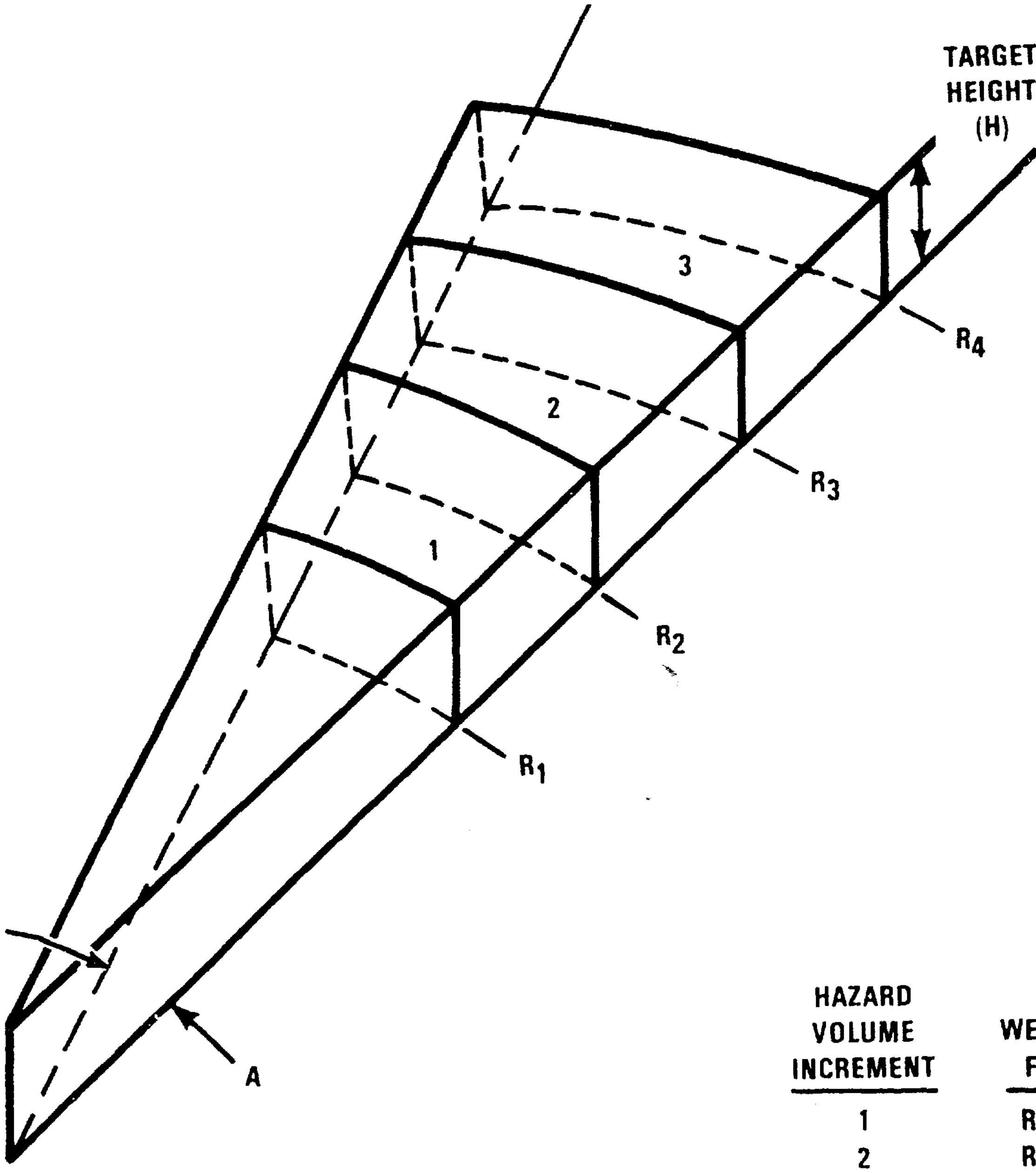
H = Constant height of the hazard volume equal to the height of the target in feet.

Collecting constants and calling the result C, the volume can now be written as follows:

$$V_1 = C(R_2^2 - R_1^2) = C(R_2 - R_1)(R_2 + R_1)$$

but

$$R_2 - R_1 = 1$$



HAZARD VOLUME INCREMENT	WEIGHTING FACTOR
1	$R_1 + 0.5$
2	$R_2 + 0.5$
3	$R_3 + 0.5$

(R IN HUNDREDS OF ft)

FIGURE G-1. COMBINING 100 FT INCREMENTS

and, therefore

$$V_1 = C(R_2 + R_1)$$

The volume of the 100-ft increment is therefore proportional to the sum of its maximum and minimum ranges in hundreds of feet. The proportionality factors for the two remaining 100-ft increments is:

$$V_2 \sim (R_3 + R_2)$$

$$V_3 \sim (R_4 + R_3)$$

If we divide each proportionality factor by the same constant then the final weighting will not be changed. Dividing each factor by two results in the weighting factor being proportional to the midrange of each 100-ft increment. Expressing the midrange in hundreds of feet, the weighting factor for an increment like 300 to 400 ft would be 3.5; for 400 to 500 ft the weighting factor would be 4.5, and so forth.

As a practical example, suppose we wished to combine three 100-ft increments from 300 to 600 ft into one 300-ft increment. Further suppose the following:

Range Increment	Density	Weighting Factor
300-400	0.6	3.5
400-500	0.4	4.5
500-600	0.3	5.5

then the weighted average combined density would be:

$$D_{300-600} = \frac{0.6\,(3.5) + 0.4\,(4.5) + 0.3\,(5.5)}{3.5 + 4.5 + 5.5} = 0.4111$$

This example could serve equally well for combining probability of hit. For comparison, the unweighted average would be 0.4333.

APPENDIX H

PROGRAM TEST CASES

INTRODUCTION

There are two tests cases: one for the MONTE CARLO option (Table H-1) and one for the FULL FACTORIAL option (Table H-2). Table H-3 contains the fragmentation data used for both test cases. Note in the beginning of Tables H-1 and H-2 that the input data is not in the same order that it is entered in the program (see BLOCK-2 of LISTING B-1 in APPENDIX B).

TABLES H-1 AND H-2

These tables are similar; they only differ in the way values are specified for the seven random variables listed near the end of the input data for the FULL FACTORIAL option, Table H-2. The test for the FULL FACTORIAL option is designed to cover all aspects of the FRAGHAZ program except crosswind and those input paths unique to the MONTE CARLO option. This was done in anticipation of the possibility that the user might be unable to satisfy the portability test for the random number generator given in Appendix F. If the portability test cannot be satisfied, then the MONTE CARLO option will have to be checked with hand cases using a random number generator specified by the user.

Tables H-1 and H-2 are divided into three parts. Part 1 contains the input data for the tests and a few statements which identify the current version of the program; e.g., "Run contains fragment ricochet routine." A full description of the input data is contained in the discussion of BLOCKS 1 and 2 in the DETAILED PROGRAM DESCRIPTION Section of the main body. Note that in the MONTE CARLO option test we used the seed 1234 for the random number generator. This is necessary if the user is to obtain the same results shown in Table H-1.

The second part of Tables H-1 and H-2 contains the initial and final conditions for each trajectory in each replication (MONTE CARLO option) or treatment (FULL FACTORIAL option). Each replication or treatment has an associated soil constant, site altitude, and wind speed. These three values pertain to all trajectories in the replication or treatment. The headings for the trajectory tables are explained as follows:

FRAG	-	Fragment number
E	-	Initial elevation angle (degrees)
WT	-	Weight of the fragment in grains
A/M	-	average presented area to mass ratio for the fragment (in.^{2}/lb)
IV	-	Initial velocity of the fragment (ft/s)
CD	-	Drag coefficient for the fragment at a Mach Number of approximately 0.1. A full discussion of drag coefficients is given in the discussion for BLOCK 9 of the DETAILED PROGRAM DESCRIPTION Section in the main body.
DISTN	-	Distance in feet at impact; final impact for a ricocheting fragment. It is equal to the square root of the sum of squares of range (DI(3)) and crossrange (DI(7)).

VF - Velocity at impact; final impact for a ricocheting fragment. (ft/s)

KE - Kinetic energy (ft-lbs) at impact; final impact for a ricocheting fragment.

TOF - Time of flight for the complete trajectory (s)

EF - The absolute value of the elevation angle at impact; final impact for a ricocheting fragment. (deg)

RANGE - Range component of distance at impact; final impact for a ricocheting fragment (DI (3)). (ft)

XRN - Crossrange at impact; final impact for a ricocheting fragment (DI (7)). (ft)

XA - Crossrange angle (deg). It is equal to the arctan of crossrange (XRN) divided by range (DI (3)).

XD - Displacement integration step at the beginning of the trajectory or for the last ricochet. (ft)

AR - Area ratio. This is the ratio of the maximum presented area to the average presented area which is used to establish the minimum and maximum values of drag coefficient at a Mach Number of approximately 0.1. See the comments for CD above.

HO - Height of the origin above ground level at the beginning of the trajectory. (ft)

RB - Number of ricochets (rebounds) for the trajectory.

The third part of Tables H-1 and H-2 consists of the 12 final output tables; three each for range increments of 100, 200, 300 and 400 ft. These final output tables are described in the discussion of BLOCKS-22, 23 and 24 in the DETAILED PROGRAM DESCRIPTION Section of the main body.

Table H-3 contains the fragmentation data for both the MONTE CARLO and FULL FACTORIAL tests. The table is divided into three parts:

Part 1 - The first 13 values in the table are the fragment multipliers as described in Appendix D. Each multiplier represents the effective number of fragments for one deg of azimuth and one unit or interaction area. The first multiplier is for polar zone 0 to 10 deg, the second for polar zone 10 to 20 deg and so on to the thirteenth multiplier which is for polar zone 120 to 130 deg.

Part 2 - The next five lines contain the five characteristics for each of the five fragments used in the tests. The five values for each fragment are described as follows:

Value 1 - The upper angle for the 10 deg polar zone containing the fragment. For example an entry of 40 would specify polar zone 30 to 40 deg. Remember that the elevation zones are derived from the polar zones as follows:

$$EL = 90 - PA$$

where

EL - The lower limit of the 10 deg elevation zone. EL may be as negative as -40.
PA - Upper limit of the 10 deg polar zone.

Value 2 - Weight of the fragment in grains.

Value 3 - The average presented area to mass ratio (in^2/lb) which is used in drag calculations.

Value 4 - Average initial fragment velocity (ft/s).

Value 5 - The ratio of maximum presented area to average presented area used to calculate the drag coefficient at a Mach Number of approximately 0.1.

Part 3 - The last seven lines in Table H-3 are the factor levels for the seven random variables used in the FULL FACTORIAL option only. The values have been selected to check all paths in the program except crosswind and those paths unique to the MONTE CARLO option. The variables associated with each line are:

Line	Random Variable
1	Soil Constant
2	Height of Origin
3	Initial Elevation Angle
4	Initial Velocity
5	Drag Coefficient
6	Site Altitude
7	Wind Speed

The "a" at the end of each line will produce a READ error in line 262 as shown in the FRAGHAZ program listing in Appendix B. After encountering the error the program will skip to the next factor level line to read the factor levels for the next random variable. The factor levels are given as decimal fractions to indicate how far above the random variable minimum the value of the random variable lies. For example, if the range of uncertainty for a random variable were 10 to 20, the factor level 0.4 would define a value of 14. The initial velocity is an exception since this random variable is distributed normally. The factor levels for initial velocity are given in standard deviations.

In comparing the user's results with Tables H-1 and H-2, the user may find some small differences due to differences in computer word size and library functions such as LOG and EXP. Generally, the user should expect the following differences:

Trajectory Tables - Almost always exact - may be off by one in the last digit.

Output Table 1 - Number of fragments should almost always be exact - may be off by one or two in the last digit. For density and probability of hit, values should be good to the fifth decimal place.

Output Table 2 - Values should be good to the fourth decimal place.

Output Table 3 - For density, the values should be almost exact - may be off by one or two in the last digit. For probability of hit, the number of units may be off by one in the first decimal place for number of units up to 50. For number of units greater than 50, values should be good to about one percent.

TABLE H-1. PROGRAM TEST CASE - MONTE CARLO OPTION

```
FRAGHAZ
Quantity - distance program (fragmenting munitions)


Source of frag data: DATA
Output file: LPT1
Target description: STANDING MAN

Minimum soil constant= 2.00      Maximum soil constant= 2.00
MONTE-CARLO OPTION

3-D fragment trajectories, 3-D man, 2-D wind
CD is a function of fragment max to avg presented area ratio
Run contains fragment ricochet routine
Variable air density, altitude, and sound speed
Ejection zone size=  10 degrees
Azimuth sector size= 10 degrees
Number of units or interaction areas=      46
Number of fragment multipliers=  13
Fragment hazard criterion=  58.0 ft-lbs
Percentile= 80
MONTE CARLO SEED=        1234
Minimum altitude of ammo storage site=  1000.000 feet
Maximum altitude of ammo storage site=  1000.000 feet
Height of ammo stack=    4.50 feet
Stack inert ground standoff=     .50 feet
Number of fragments=       5
Maximum computation range: 2400 feet
Dimensions of the target (feet): HM=   5.72  WM=   1.00  DM=    .55
Hazard density criterion=  .0016667 frags/sqft
Hazard probability of hit criterion=  .0100000
Minimum wind speed=  30.00 feet/second
Maximum wind speed=  30.00 feet/second
Wind direction=  45.00 deg (0=tailwind)


Fragment multipliers
 .01000  .02000  .03000  .04000  .05000  .06000  .07000  .08000  .09000
 .10000  .11000  .12000  .13000

NO. OF REPLICATIONS =  16
NO. OF REPLICATIONS PRINTED =  16


                              REPLICATION (    1 )

Soil constant= 2.000  Altitude=  1000.000 feet  Wind speed=  30.000 feet/second
```

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	1.96	1000.0	16.00	1967	.51	1126	29.6	2.0	4.69	17.1	1124	64	3.3	49	1.10	2.24	3
2	-7.58	1000.0	12.00	2974	.80	1207	120.2	32.1	4.43	31.0	1204	83	3.9	36	1.25	2.14	1
3	86.50	500.0	10.00	1874	.98	546	117.0	15.2	16.31	75.0	438	325	36.6	50	1.70	4.39	0
4	11.78	500.0	7.00	1012	.66	1697	158.5	27.9	5.88	31.2	1694	90	3.1	41	1.30	2.43	0
5	-37.70	500.0	6.00	3116	.94	2	3103.0	9999.9	.00	37.7	2	0	.0	1	1.50	1.18	0

REPLICATION (2)

Soil constant= 2.000 Altitude= 1000.000 feet Wind speed= 30.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HD	RB
1	5.71	1000.0	16.00	2101	.59	1046	136.2	41.2	3.34	20.7	1044	61	3.3	30	1.10	3.97	0
2	-.60	1000.0	12.00	3037	.73	1234	43.0	4.1	4.61	13.9	1232	69	3.2	44	1.25	2.14	4
3	86.41	500.0	10.00	1994	1.23	507	105.2	12.3	15.24	73.3	404	307	37.3	50	1.70	3.55	0
4	15.24	500.0	7.00	1024	.81	1619	139.4	21.6	6.65	40.5	1616	109	3.9	46	1.30	3.41	0
5	-37.65	500.0	6.00	2847	.96	3	2824.8	8857.4	.00	37.6	3	0	.0	2	1.50	2.15	0

REPLICATION (3)

Soil constant= 2.000 Altitude= 1000.000 feet Wind speed= 30.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HD	RB
1	5.81	1000.0	16.00	1942	.56	1055	140.3	43.7	3.33	19.9	1053	60	3.2	30	1.10	1.87	0
2	-5.78	1000.0	12.00	2973	.57	1467	144.6	46.4	4.49	26.1	1465	83	3.2	34	1.25	2.77	1
3	80.31	500.0	10.00	1983	1.46	584	97.5	10.6	14.22	71.7	509	288	29.5	50	1.70	3.99	0
4	11.69	500.0	7.00	994	.77	1530	148.6	24.5	5.57	31.4	1528	87	3.3	41	1.30	1.00	0
5	-32.99	500.0	6.00	2897	.99	4	2865.3	9113.5	.00	33.0	4	0	.0	3	1.50	2.61	0

REPLICATION (4)

Soil constant= 2.000 Altitude= 1000.000 feet Wind speed= 30.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HD	RB
1	4.98	1000.0	16.00	2052	.49	1102	157.0	54.7	3.14	16.8	1101	56	2.9	29	1.10	1.82	0
2	-5.66	1000.0	12.00	2964	.71	1281	130.7	37.9	4.21	27.0	1279	79	3.5	34	1.25	2.02	1
3	85.97	500.0	10.00	1846	1.22	510	105.8	12.4	15.11	73.4	411	303	36.4	50	1.70	1.85	0
4	16.90	500.0	7.00	1022	.92	1527	131.3	19.1	6.84	44.1	1523	124	4.3	48	1.30	.73	0
5	-38.76	500.0	6.00	2965	.95	3	2938.7	9586.3	.00	38.8	3	0	.0	3	1.50	2.54	0

REPLICATION (5)

Soil constant= 2.000 Altitude= 1000.000 feet Wind speed= 30.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HD	RB
1	5.35	1000.0	16.00	2021	.52	1089	150.0	50.0	3.23	18.0	1087	58	3.0	29	1.10	1.11	0
2	-2.98	1000.0	12.00	3090	.89	1068	131.9	38.6	3.20	20.0	1066	60	3.2	30	1.25	3.87	1
3	80.50	500.0	10.00	2067	1.32	614	102.0	11.5	14.78	72.5	536	299	29.1	50	1.70	1.96	0
4	15.13	500.0	7.00	1020	.78	1649	141.6	22.2	6.68	40.0	1646	109	3.8	46	1.30	3.06	0
5	-39.44	500.0	6.00	2899	.85	4	2869.1	9137.7	.00	39.4	4	0	.0	4	1.50	3.22	0

REPLICATION (6)

Soil constant= 2.000 Altitude= 1000.000 feet Wind speed= 30.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HD	RB
1	4.18	1000.0	16.00	2194	.49	1078	167.8	62.5	2.85	14.3	1076	51	2.7	27	1.10	2.09	0
2	-3.86	1000.0	12.00	2986	.74	1219	136.0	41.1	3.70	22.6	1217	69	3.2	31	1.25	3.81	1
3	85.18	500.0	10.00	1940	.94	591	118.8	15.7	16.55	75.2	491	330	33.9	50	1.70	4.32	0
4	18.37	500.0	7.00	988	.93	1528	130.3	18.8	7.18	46.8	1523	121	4.5	50	1.30	4.47	0
5	-33.35	500.0	6.00	2996	.85	1	2989.6	9921.2	.00	33.3	1	0	.0	0	1.50	.56	0

REPLICATION (7)

Soil constant= 2.000 Altitude= 1000.000 feet Wind speed= 30.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	1.53	1000.0	16.00	2028	.52	1131	35.4	2.8	4.66	15.8	1129	65	3.3	47	1.10	3.47	3
2	-5.89	1000.0	12.00	2977	.61	1403	139.4	43.1	4.41	26.6	1401	82	3.3	34	1.25	3.40	1
3	86.86	500.0	10.00	1895	1.38	471	99.8	11.1	14.52	72.4	369	293	38.4	50	1.70	1.45	0
4	16.55	500.0	7.00	947	.74	1692	143.6	22.9	7.06	41.8	1688	113	3.8	48	1.30	2.94	0
5	-31.29	500.0	6.00	2927	1.35	7	2863.1	9099.2	.00	31.3	7	0	.0	6	1.50	4.04	0

REPLICATION (8)

Soil constant= 2.000 Altitude= 1000.000 feet Wind speed= 30.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	5.23	1000.0	16.00	1998	.55	1042	146.8	47.9	3.13	17.9	1041	56	3.1	29	1.10	1.31	0
2	-8.17	1000.0	12.00	2956	.89	1131	113.6	28.6	4.44	32.9	1128	83	4.2	37	1.25	.56	1
3	86.82	500.0	10.00	1782	1.43	460	98.3	10.7	14.25	72.2	361	286	38.5	50	1.70	3.17	0
4	10.89	500.0	7.00	997	.83	1443	146.9	24.0	5.22	29.7	1441	81	3.2	39	1.30	.91	0
5	-31.66	500.0	6.00	2923	.96	3	2898.6	9326.3	.00	31.7	3	0	.0	3	1.50	1.95	0

REPLICATION (9)

Soil constant= 2.000 Altitude= 1000.000 feet Wind speed= 30.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	1.26	1000.0	16.00	1983	.51	1141	47.5	5.0	4.59	13.4	1139	66	3.3	43	1.10	1.50	3
2	-2.71	1000.0	12.00	3053	.70	1212	149.8	49.8	3.30	18.2	1210	61	2.9	29	1.25	3.57	1
3	80.90	500.0	10.00	1964	1.65	539	92.3	9.5	13.62	70.7	463	276	30.8	50	1.70	2.96	0
4	16.05	500.0	7.00	1086	.82	1661	138.1	21.2	6.94	42.7	1657	116	4.0	47	1.30	2.12	0
5	-34.24	500.0	6.00	3071	.93	1	3064.1	9999.9	.00	34.2	1	0	.0	0	1.50	.59	0

REPLICATION (10)

Soil constant= 2.000 Altitude= 1000.000 feet Wind speed= 30.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	8.13	1000.0	16.00	2069	.62	1100	121.3	32.7	4.04	28.1	1098	75	3.9	35	1.10	1.29	0
2	-3.27	1000.0	12.00	3011	.88	1083	129.5	37.3	3.34	21.3	1081	63	3.3	30	1.25	3.00	1
3	85.17	500.0	10.00	2066	1.68	472	91.6	9.3	13.77	70.7	380	280	36.4	50	1.70	4.07	0
4	10.79	500.0	7.00	1040	.80	1495	148.9	24.6	5.30	29.8	1493	83	3.2	39	1.30	1.58	0
5	-37.10	500.0	6.00	3068	.95	4	3032.6	9999.9	.00	37.1	4	0	.0	4	1.50	3.11	0

REPLICATION (11)

Soil constant= 2.000 Altitude= 1000.000 feet Wind speed= 30.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	5.42	1000.0	16.00	1965	.59	1013	141.2	44.3	3.14	18.6	1011	56	3.2	30	1.10	1.15	0
2	-8.10	1000.0	12.00	3075	.69	1338	126.8	35.7	4.78	31.8	1335	89	3.8	37	1.25	1.58	1
3	84.21	500.0	10.00	2003	1.60	494	93.6	9.7	13.88	71.1	406	281	34.7	50	1.70	1.55	0
4	11.64	500.0	7.00	1027	.86	1453	141.5	22.2	5.47	32.5	1451	87	3.4	41	1.30	3.48	0
5	-38.01	500.0	6.00	2852	1.10	4	2817.4	8811.3	.00	38.0	4	0	.0	4	1.50	3.09	0

REPLICATION (12)

Soil constant= 2.000 Altitude= 1000.000 feet Wind speed= 30.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HD	RB
1	5.78	1000.0	16.00	1954	.56	1057	140.1	43.6	3.34	20.0	1055	60	3.3	30	1.10	2.61	0
2	-1.09	1000.0	12.00	2891	.61	1329	62.3	8.6	4.53	13.6	1327	67	2.9	43	1.25	2.59	3
3	89.53	500.0	10.00	2000	1.24	443	104.7	12.2	15.23	73.4	319	307	43.8	50	1.70	4.19	0
4	13.15	500.0	7.00	973	.95	1385	133.1	19.7	5.70	36.0	1382	92	3.8	43	1.30	3.46	0
5	-35.67	500.0	6.00	2850	1.13	6	2796.5	8680.7	.00	35.7	6	0	.0	6	1.50	4.43	0

REPLICATION (13)

Soil constant= 2.000 Altitude= 1000.000 feet Wind speed= 30.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HD	RB
1	4.76	1000.0	16.00	2101	.55	1048	150.5	50.3	3.05	17.2	1047	55	3.0	28	1.10	4.43	0
2	-4.99	1000.0	12.00	3068	.63	1384	140.8	44.0	4.21	25.0	1381	78	3.2	33	1.25	3.80	1
3	81.13	500.0	10.00	1976	1.15	637	108.5	13.1	15.40	73.6	557	309	29.1	50	1.70	1.13	0
4	19.01	500.0	7.00	944	.66	1878	149.6	24.8	7.99	45.8	1874	128	3.9	51	1.30	2.84	0
5	-35.51	500.0	6.00	2865	1.31	2	2842.5	8969.2	.00	35.5	2	0	.0	2	1.50	1.62	0

REPLICATION (14)

Soil constant= 2.000 Altitude= 1000.000 feet Wind speed= 30.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HD	RB
1	4.66	1000.0	16.00	1927	.52	1036	157.2	54.9	2.95	15.8	1035	52	2.9	28	1.10	2.37	0
2	-6.36	1000.0	12.00	2858	.85	1144	119.5	31.7	4.11	28.8	1142	77	3.9	35	1.25	1.5[illegible]	1
3	86.10	500.0	10.00	1925	1.64	455	92.6	9.5	13.74	71.0	360	278	37.7	50	1.70	3.33	0
4	12.35	500.0	7.00	976	.85	1457	141.2	22.1	5.61	33.4	1455	89	3.5	42	1.30	1.57	0
5	-33.26	500.0	6.00	2849	1.07	2	2830.7	8894.7	.00	33.3	2	0	.0	2	1.50	1.47	0

REPLICATION (15)

Soil constant= 2.000 Altitude= 1000.000 feet Wind speed= 30.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HD	RB
1	3.24	1000.0	16.00	1987	.47	1124	88.9	17.5	3.82	14.3	1123	57	2.9	43	1.10	2.47	1
2	-7.28	1000.0	12.00	2958	.87	1136	116.3	30.0	4.24	30.5	1134	80	4.0	36	1.25	2.69	1
3	89.37	500.0	10.00	1999	1.31	438	102.1	11.6	14.94	72.9	318	301	43.5	50	1.70	3.94	0
4	18.65	500.0	7.00	979	.69	1848	147.3	24.1	7.86	45.6	1843	127	4.0	51	1.30	.84	0
5	-32.22	500.0	6.00	2788	1.01	2	2774.4	8544.5	.00	32.2	2	0	.0	1	1.50	1.15	0

REPLICATION (16)

Soil constant= 2.000 Altitude= 1000.000 feet Wind speed= 30.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HD	RB
1	4.84	1000.0	16.00	2003	.54	1042	150.3	50.2	3.06	17.2	1040	55	3.0	28	1.10	4.37	0
2	-4.43	1000.0	12.00	3084	.85	1140	125.1	34.7	3.71	24.6	1138	70	3.5	32	1.25	4.40	1
3	80.45	500.0	10.00	2012	1.62	554	93.1	9.6	13.73	70.9	479	279	30.2	50	1.70	1.75	0
4	19.97	500.0	7.00	995	.90	1581	131.5	19.2	7.62	49.2	1576	129	4.7	52	1.30	1.42	0
5	-38.26	500.0	6.00	2893	1.06	5	2847.3	8999.0	.00	38.3	5	0	.0	5	1.50	4.16	0

TABLE 1 Increment = 100 feet Number of Units= 46

Distance (feet) From	To	Total No.	Total Density Frags/sqft	Total P-hit	Hazard No.	Hazard Density Frags/sqft	Hazard P-hit	Total Number of Final Ground Impacts, 10 Degree Azimuth Sector: Min	Avg	Max
0	100	188.60	1.019557	.995384	188.60	1.019557	.995384	59.80	59.80	59.80
100	200	25.30	.087241	.298157	25.30	.087241	.298157	.00	.00	.00
200	300	8.34	.022060	.091629	8.34	.022060	.091629	.00	.00	.00
300	400	2.88	.005699	.025393	2.88	.005699	.025393	.00	.00	.00
400	500	4.89	.004892	.022179	2.88	.004627	.021573	.00	2.01	4.60
500	600	2.01	.000216	.000476	.00	.000000	.000000	.00	2.01	4.60
600	700	3.16	.002345	.011969	2.59	.002293	.011855	.00	.57	4.60
700	800	10.64	.006570	.034878	10.64	.006570	.034878	.00	.00	.00
800	900	8.05	.003840	.020700	7.62	.003601	.019421	.00	.00	.00
900	1000	13.23	.004382	.023962	6.76	.002525	.013739	.00	.00	.00
1000	1100	52.90	.011338	.061625	6.11	.001447	.008013	.00	31.63	87.40
1100	1200	38.52	.006930	.037277	.00	.000000	.000000	.00	27.03	87.40
1200	1300	17.25	.002738	.014844	.00	.000000	.000000	.00	14.38	46.00
1300	1400	13.80	.001695	.008994	.00	.000000	.000000	.00	10.93	82.80
1400	1500	14.95	.001107	.005780	.00	.000000	.000000	.00	14.95	46.00
1500	1600	9.20	.000484	.002216	.00	.000000	.000000	.00	9.20	36.80
1600	1700	11.50	.000598	.002857	.00	.000000	.000000	.00	11.50	36.80
1700	1800	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00
1800	1900	4.60	.000189	.000829	.00	.000000	.000000	.00	4.60	36.80
1900	2000	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00
2000	2100	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00
2100	2200	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00
2200	2300	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00
2300	2400	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00

Number of trajectories with distance greater than 2400 feet= 0

TABLE 2 Increment= 100 feet Number of Units= 46

Distance (feet)	Hazard Density (Frags/sqft): Max	80%	50%	Min	Hazard Probability of Hit: Max	80%	50%	Min
50	1.352684	1.133668	.932629	.844622	.999508	.998272	.994468	.990744
150	.325103	.176591	.000000	.000000	.843791	.635624	.000000	.000000
250	.127613	.000000	.000000	.000000	.518014	.000000	.000000	.000000
350	.091186	.000000	.000000	.000000	.406319	.000000	.000000	.000000
450	.074033	.000000	.000000	.000000	.345160	.000000	.000000	.000000
550	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
650	.036684	.000000	.000000	.000000	.189808	.000000	.000000	.000000
750	.036063	.022153	.000000	.000000	.186907	.119523	.000000	.000000
850	.024130	.000000	.000000	.000000	.129296	.000000	.000000	.000000
950	.021390	.000000	.000000	.000000	.114876	.000000	.000000	.000000
1050	.013625	.000000	.000000	.000000	.075269	.000000	.000000	.000000
1150	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1250	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1350	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1450	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1550	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1650	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1750	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1850	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1950	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2050	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2150	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2250	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2350	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000

TABLE 3 Increment= 100 feet

HAZARD DISTANCE (FEET)	NUMBER OF UNITS TO JUST EXCEED: DENSITY CRITERION MIN	DENSITY CRITERION 80%	DENSITY CRITERION 50%	DENSITY CRITERION MAX	P-HIT CRITERION MIN	P-HIT CRITERION 80%	P-HIT CRITERION 50%	P-HIT CRITERION MAX
50	.07	.08	.09	.10	.07	.08	.10	.11
150	.25	.44	999999.00	999999.00	.26	.47	999999.00	999999.00
250	.61	999999.00	999999.00	999999.00	.64	999999.00	999999.00	999999.00
350	.85	999999.00	999999.00	999999.00	.90	999999.00	999999.00	999999.00
450	1.05	999999.00	999999.00	999999.00	1.10	999999.00	999999.00	999999.00
550	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
650	2.10	999999.00	999999.00	999999.00	2.21	999999.00	999999.00	999999.00
750	2.14	3.47	999999.00	999999.00	2.24	3.64	999999.00	999999.00
850	3.19	999999.00	999999.00	999999.00	3.35	999999.00	999999.00	999999.00
950	3.59	999999.00	999999.00	999999.00	3.80	999999.00	999999.00	999999.00
1050	5.64	999999.00	999999.00	999999.00	5.92	999999.00	999999.00	999999.00
1150	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1250	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1350	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1450	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1550	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1650	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1750	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1850	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1950	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
2050	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
2150	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
2250	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
2350	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00

The 999999.00 entries signify that the number of units required is infinite,
that is, the Hazard Density and P-hit are both zero.
Hazard Density Criterion= .001667 frag/sqft Hazard P-hit Criterion= .010

TABLE 1 Increment = 200 feet Number of Units= 46

Distance (feet) From	To	Total No.	Total Density Frags/sqft	Total P-hit	Hazard No.	Hazard Density Frags/sqft	Hazard P-hit	Total Number of Final Ground Impacts 10 Degree Azimuth Sector Min	Avg	Max
0	200	213.90	.320320	.472464	213.90	.320320	.472464	59.80	59.80	59.80
200	400	11.21	.012516	.052992	11.21	.012516	.052992	.00	.00	.00
400	600	6.90	.002320	.010243	2.88	.002082	.009708	.00	4.03	9.20
600	800	13.60	.004608	.024241	13.23	.004584	.024188	.00	.57	4.60
800	1000	21.28	.004126	.022422	14.38	.003033	.016422	.00	.00	.00
1000	1200	91.43	.009034	.048898	6.11	.000690	.003824	.00	58.65	174.80
1200	1400	31.05	.002196	.011807	.00	.000000	.000000	.00	25.30	128.80
1400	1600	24.15	.000785	.003939	.00	.000000	.000000	.00	24.15	82.80
1600	1800	11.50	.000290	.001387	.00	.000000	.000000	.00	11.50	36.80
1800	2000	4.60	.000092	.000404	.00	.000000	.000000	.00	4.60	36.80
2000	2200	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00
2200	2400	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00

TABLE 2 Increment= 200 feet Number of Units= 46

Distance (feet)	Hazard Density (Frags/sqft) Max	80%	50%	Min	Hazard Probability of Hit Max	80%	50%	Min
100	.561999	.415860	.233157	.211156	.882720	.726286	.248617	.247686
300	.106364	.000000	.000000	.000000	.452858	.000000	.000000	.000000
500	.033315	.000000	.000000	.000000	.155322	.000000	.000000	.000000
700	.036351	.011959	.000000	.000000	.188254	.064030	.000000	.000000
900	.022684	.000000	.000000	.000000	.121685	.000000	.000000	.000000
1100	.006503	.000000	.000000	.000000	.035924	.000000	.000000	.000000
1300	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1500	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1700	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1900	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2100	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2300	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000

TABLE 3 Increment= 200 feet

HAZARD DISTANCE (FEET)	NUMBER OF UNITS TO JUST EXCEED — DENSITY CRITERION MIN	80%	50%	MAX	P-HIT CRITERIC. MIN	80%	50%	MAX
100	.14	.19	.34	.37	.15	.21	.38	.42
300	.73	999999.00	999999.00	999999.00	.77	999999.00	999999.00	999999.00
500	2.31	999999.00	999999.00	999999.00	2.44	999999.00	999999.00	999999.00
700	2.17	6.47	999999.00	999999.00	2.25	6.79	999999.00	999999.00
900	3.39	999999.00	999999.00	999999.00	3.57	999999.00	999999.00	999999.00
1100	11.80	999999.00	999999.00	999999.00	12.39	999999.00	999999.00	999999.00
1300	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1500	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1700	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1900	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
2100	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
2300	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00

The 999999.00 entries signify that the number of units required is infinity,
that is, the Hazard Density and P-hit are both zero.
Hazard Density Criterion= .001657 frag/sqft Hazard P-hit Criterion= .010

TABLE 1 Increment = 300 feet Number of Units= 46

Distance (feet) From	To	Total No.	Total Density Frags/sqft	Total P hit	Hazard No.	Hazard Density Frags/sqft	Hazard P-hit	Total Number of Final Ground Impacts, 10 Degree Azimuth Sector: Min	Avg	Max
0	300	222.24	.154620	.260889	222.24	.154620	.260889	59.80	59.80	59.80
300	600	9.77	.003196	.014171	5.75	.003070	.013774	.00	4.93	9.20
600	900	21.85	.004318	.027903	20.84	.004213	.022387	.00	.57	4.60
900	1200	104.65	.007631	.041378	12.87	.001244	.006814	.00	58.65	174.80
1200	1500	46.00	.001806	.005647	.00	.000000	.000000	.00	40.25	174.80
1500	1800	20.70	.000351	.001646	.00	.000000	.000000	.00	20.70	73.60
1800	2100	4.60	.000060	.000267	.00	.000000	.000000	.00	4.60	36.80
2100	2400	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00

Number of trajectories with distance greater than 2400 feet= 0

TABLE 2 Increment= 300 feet Number of Units= 46

Distance (feet)	Hazard Density (Frags/sqft) Max	80%	50%	Min	Hazard Probability of Hit Max	80%	50%	Min
150	.329562	.184827	.103625	.093247	.680105	.322794	.110496	.110083
450	.048318	.000000	.000000	.000000	.220395	.000000	.000000	.000000
750	.031734	.007384	.000000	.000000	.165981	.039841	.000000	.000000
1050	.010993	.000000	.000000	.000000	.059735	.000000	.000000	.000000
1350	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1650	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1950	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2250	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000

TABLE 3 Increment= 300 feet

HAZARD DISTANCE (FEET)	NUMBER OF UNITS TO JUST EXCEED — DENSITY CRITERION MIN	80%	50%	MAX	P-HIT CRITERION MIN	80%	50%	MAX
150	.24	.42	.75	.87	.26	.47	.85	.94
450	1.60	999999.00	999999.00	999999.00	1.69	999999.00	999999.00	999999.00
750	2.43	10.39	999999.00	999999.00	2.55	10.92	999999.00	999999.00
1050	6.98	999999.00	999999.00	999999.00	7.36	999999.00	999999.00	999999.00
1350	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1650	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1950	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
2250	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00

The 999999.00 entries signify that the number of units required is infinite,
that is, the Hazard Density and P-hit are both zero.
Hazard Density Criterion= .0[illegible]667 frag/sqft Hazard P-hit Criterion= .010

TABLE 4 Increment = 400 feet Number of Units= 46

Distance (feet) From	To	Total No.	Total Density Frags/sqft	Total P-hit	Hazard No.	Hazard Density Frags/sqft	Hazard P-hit	Total Number of Final Ground Impacts — 10 Degree Azimuth Sector Min	Avg	Max
0	400	225.11	.089467	.157860	225.11	.089467	.157860	59.80	59.80	59.80
400	800	20.70	.003655	.018469	18.10	.003542	.018155	.00	4.60	13.90
800	1200	112.70	.006825	.076884	20.49	.001745	.009493	.00	58.55	174.80
1200	1600	55.70	.001440	.007597	.00	.000000	.000000	.00	49.45	211.60
1600	2000	16.10	.000186	.000858	.00	.000000	.000000	.00	16.10	73.50
2000	2400	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00

Number of trajectories with distance greater than 2400 feet= 0

TABLE 2 Increment= 400 feet Number of Units= 46

Distanr (feet)	Max	80%	50%	Min	Max	80%	50%	Min
200	.225273	.103965	.058289	.052789	.560324	.181572	.062154	.061921
600	.035086	.006923	.000000	.000000	.174532	.037351	.000000	.000000
1000	.013784	.000000	.000000	.000000	.074516	.000000	.000000	.000000
1400	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1800	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2200	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000

TABLE 3 Increment= 400 feet

HAZARD	NUMBER OF UNITS TO JUST EXCEED							
DISTANCE	DENSITY CRITERION				P-HIT CRITERION			
(FEET)	MIN	80%	50%	MAX	MIN	80%	50%	MAX
200	.35	.75	1.33	1.46	.38	.83	1.51	1.67
600	2.20	11.08	999999.00	999999.00	2.31	11.64	999999.00	999999.00
1000	5.57	999999.00	999999.00	999999.00	5.87	999999.00	999999.00	999999.00
1400	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1800	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
2200	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00

The 999999.00 entries signify that the number of units required is infinite,
that is, the Hazard Density and P-hit are both zero.

Hazard Density Criterion= .001667 frag/sqft Hazard P-hit Criterion= .010

TABLE H-2. PROGRAM TEST CASE - FULL FACTORIAL OPTION

```
FRAGHAZ
quantity - distance program (fragmenting munitions)


Source of frag data: DATA
Output file: LPT1
Target description: STANDING MAN

Minimum soil constant=  .50     Maximum soil constant= 4.00
FULL FACTORIAL OPTION

3-D fragment trajectories, 3-D man, 2-D wind
CD is a function of fragment max to avg presented area ratio
Run contains fragment ricochet routine
Variable air density, altitude, and sound speed
Ejection zone size=  10 degrees
Azimuth sector size= 10 degrees
Number of units or interaction areas=     46
Number of fragment multipliers=  13
Fragment hazard criterion=  58.0 ft-lbs
Percentile= 90
Minimum altitude of ammo storage site=      .000 feet
Maximum altitude of ammo storage site=  5000.000 feet
Height of ammo stack=   4.50 feet
Stack inert ground standoff=    .50 feet
Number of fragments=      5
Maximum computation range: 2400 feet
Dimensions of the target (feet): HM=   5.72  WM=   1.00   DM=    .55
Hazard density criterion=  .0016667 frags/sqft
Hazard probability of hit criterion=  .0100000
Minimum wind speed=    .00 feet/second
Maximum wind speed=  30.00 feet/second
Wind direction=    .00 deg (0=tailwind)


Fragment multipliers
 .01000  .02000  .03000  .04000  .05000  .06000  .07000  .08000  .09000
 .10000  .11000  .12000  .13000


FACTOR LEVELS
SOIL CONSTANT:          .1000   .2500   .6000   .8000
HEIGHT OF ORIGIN:       .5000
ELEVATION ANGLE:        .0000   .9999
INITIAL VELOCITY:      1.2000
DRAG COEFFICIENT:       .5000
ALTITUDE:               .5000
WIND SPEED:             .0000   .9000

NO. OF TREATMENTS =  16
NO. OF TREATMENTS PRINTED =  16
```

TREATMENT (1)

Soil constant= .850 Altitude= 2500.000 feet Wind speed= .000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	IRN	IA	XD	AR	HO	RB
1	.01	1000.0	16.00	2084	.56	983	74.5	12.3	3.61	12.4	983	0	.0	40	1.10	2.50	3
2	-10.00	1000.0	12.00	3126	.74	1209	112.0	27.9	9.82	76.1	1209	0	.0	64	1.25	2.50	1
3	80.00	500.0	10.00	2084	1.28	265	100.9	11.3	15.18	89.3	265	0	.0	50	1.70	2.50	0
4	10.00	500.0	7.00	1042	.80	1403	135.9	20.5	5.08	31.7	1403	0	.0	38	1.30	2.50	0
5	-40.00	500.0	6.00	3126	1.04	3	3098.4	9999.9	.00	40.0	3	0	.0	3	1.50	2.50	0

TREATMENT (2)

Soil constant= .850 Altitude= 2500.000 feet Wind speed= 27.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	IRN	IA	XD	AR	HO	RB
1	.01	1000.0	16.00	2084	.56	1147	49.3	5.4	5.00	25.0	1147	0	.0	58	1.10	2.50	4
2	-10.00	1000.0	12.00	3126	.74	1468	121.5	32.8	9.91	63.9	1468	0	.0	64	1.25	2.50	[illegible]
3	80.00	500.0	10.00	2084	1.28	657	104.7	12.2	15.20	74.4	657	0	.0	50	1.70	2.50	0
4	10.00	500.0	7.00	1042	.80	1535	158.6	27.9	5.13	27.0	1535	0	.0	38	1.30	2.50	0
5	-40.00	500.0	6.00	3126	1.04	3	3098.7	9999.9	.00	40.0	3	0	.0	3	1.50	2.50	0

TREATMENT (3)

Soil constant= .850 Altitude= 2500.000 feet Wind speed= .000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	IRN	IA	XD	AR	HO	RB
1	10.00	1000.0	16.00	2084	.56	1162	104.6	24.3	4.80	40.1	1162	0	.0	38	1.10	2.50	0
2	-.01	1000.0	12.00	3126	.74	1134	79.7	14.1	3.61	11.4	1134	0	.0	38	1.25	2.50	3
3	89.99	500.0	10.00	2084	1.28	0	100.9	11.3	15.49	90.0	0	0	.0	50	1.70	2.50	0
4	20.00	500.0	7.00	1042	.80	1625	126.9	17.9	8.06	56.8	1625	0	.0	52	1.30	2.50	0
5	-30.00	500.0	6.00	3126	1.04	4	3090.5	9999.9	.00	30.0	4	0	.0	4	1.50	2.50	0

TREATMENT (4)

Soil constant= .850 Altitude= 2500.000 feet Wind speed= 27.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	IRN	IA	XD	AR	HO	RB
1	10.00	1000.0	16.00	2084	.56	1292	126.2	35.4	4.83	32.4	1292	0	.0	38	1.10	2.50	0
2	-.01	1000.0	12.00	3126	.74	1307	54.2	6.5	5.00	22.3	1307	0	.0	55	1.25	2.50	4
3	89.99	500.0	10.00	2084	1.28	396	104.5	12.1	15.40	75.1	396	0	.0	50	1.70	2.50	0
4	20.00	500.0	7.00	1042	.80	1836	143.3	22.8	8.15	48.3	1836	0	.0	57	1.30	2.50	0
5	-30.00	500.0	6.00	3126	1.04	4	3091.0	9999.9	.00	30.0	4	0	.0	4	1.50	2.50	0

TREATMENT (5)

Soil constant= 1.375 Altitude= 2500.000 feet Wind speed= .000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	IRN	IA	XD	AR	HO	RB
1	.01	1000.0	16.00	2084	.56	1009	65.8	10.5	3.77	16.0	1009	0	.0	45	1.10	2.50	3
2	-10.00	1000.0	12.00	3126	.74	1363	108.1	25.9	8.41	69.7	1363	0	.0	57	1.25	2.50	1
3	80.00	500.0	10.00	2084	1.28	265	100.9	11.3	15.18	89.3	265	0	.0	50	1.70	2.50	0
4	10.00	500.0	7.00	1042	.80	1403	135.9	20.5	5.08	31.7	1403	0	.0	38	1.30	2.50	0
5	-40.00	500.0	6.00	3126	1.04	3	3098.4	9999.9	.00	40.0	3	0	.0	3	1.50	2.50	0

TREATMENT (6)

Soil constant= 1.375 Altitude= 2500.000 feet Wind speed= 27.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	.01	1000.0	16.00	2084	.56	1167	36.9	3.0	5.60	41.4	1167	0	.0	67	1.10	2.50	4
2	-10.00	1000.0	12.00	3126	.74	1529	120.2	32.1	8.48	57.8	1529	0	.0	57	1.25	2.50	1
3	80.00	500.0	10.00	2084	1.28	657	104.7	12.2	15.20	74.4	657	0	.0	50	1.70	2.50	0
4	10.00	500.0	7.00	1042	.80	1535	158.6	27.9	5.13	27.0	1535	0	.0	38	1.30	2.50	0
5	-40.00	500.0	6.00	3126	1.04	3	3098.7	9999.9	.00	40.0	3	0	.0	3	1.50	2.50	0

TREATMENT (7)

Soil constant= 1.375 Altitude= 2500.000 feet Wind speed= .000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	10.00	1000.0	16.00	2084	.56	1162	104.6	24.3	4.80	40.1	1162	0	.0	36	1.10	2.50	0
2	-.01	1000.0	12.00	3126	.74	1161	73.3	11.9	3.97	14.9	1161	0	.0	43	1.25	2.50	3
3	89.99	500.0	10.00	2084	1.28	0	100.9	11.3	15.40	90.0	0	0	.0	50	1.70	2.50	0
4	20.00	500.0	7.00	1042	.80	1625	126.9	27.9	6.06	56.9	1625	0	.0	52	1.30	2.50	0
5	-30.00	500.0	6.00	3126	1.04	4	3090.5	9999.9	.00	30.0	4	0	.0	4	1.50	2.50	0

TREATMENT (8)

Soil constant= 1.375 Altitude= 2500.000 feet Wind speed= 27.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	10.00	1000.0	16.00	2084	.56	1292	126.2	35.4	4.83	32.4	1292	0	.0	38	1.10	2.50	0
2	-.01	1000.0	12.00	3126	.74	1332	42.3	4.0	5.66	36.4	1332	0	.0	66	1.25	2.50	4
3	89.99	500.0	10.00	2084	1.28	396	104.5	12.1	15.40	75.1	396	0	.0	50	1.70	2.50	0
4	20.00	500.0	7.00	1042	.80	1836	143.3	22.8	8.15	48.3	1836	0	.0	52	1.30	2.50	0
5	-30.00	500.0	6.00	3126	1.04	4	3091.0	9999.9	.00	30.0	4	0	.0	4	1.50	2.50	0

TREATMENT (9)

Soil constant= 2.600 Altitude= 2500.000 feet Wind speed= .000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	.01	1000.0	16.00	2084	.56	1011	24.4	1.3	4.40	20.6	1011	0	.0	53	1.10	2.50	4
2	-10.00	1000.0	12.00	3126	.74	1239	102.9	23.5	5.50	47.0	1239	0	.0	42	1.25	2.50	1
3	80.00	500.0	10.00	2084	1.28	265	100.9	11.3	15.18	89.3	265	0	.0	50	1.70	2.50	0
4	10.00	500.0	7.00	1042	.80	1403	135.9	20.5	5.08	31.7	1403	0	.0	38	1.30	2.50	0
5	-40.00	500.0	6.00	3126	1.04	3	3098.4	9999.9	.00	40.0	3	0	.0	3	1.50	2.50	0

TREATMENT (10)

Soil constant= 2.600 Altitude= 2500.000 feet Wind speed= 27.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	.01	1000.0	16.00	2084	.56	1156	45.3	4.6	4.85	14.9	1156	0	.0	46	1.10	2.50	4
2	-10.00	1000.0	12.00	3126	.74	1388	122.6	33.4	5.54	38.1	1388	0	.0	42	1.25	2.50	1
3	80.00	500.0	10.00	2084	1.28	657	104.7	12.2	15.20	74.4	657	0	.0	50	1.70	2.50	0
4	10.00	500.0	7.00	1042	.80	1535	158.6	27.9	5.13	27.0	1535	0	.0	38	1.30	2.50	0
5	-40.00	500.0	6.00	3126	1.04	3	3098.7	9999.9	.00	40.0	3	0	.0	3	1.50	2.50	0

TREATMENT (11)

Soil constant= 2.600 Altitude= 2500.000 feet Wind speed= .000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	10.00	1000.0	16.00	2084	.56	1162	104.6	24.3	4.80	40.1	1162	0	.0	38	1.10	2.50	0
2	-.01	1000.0	12.00	3126	.74	1166	27.0	1.6	4.48	19.6	1166	0	.0	52	1.25	2.50	4
3	89.99	500.0	10.00	2084	1.28	0	100.9	11.3	15.40	90.0	0	0	.0	50	1.70	2.50	0
4	20.00	500.0	7.00	1042	.80	1625	126.9	17.9	8.06	56.8	1625	0	.0	52	1.30	2.50	0
5	-30.00	500.0	6.00	3126	1.04	4	3090.5	9999.9	.00	30.0	4	0	.0	4	1.50	2.50	0

TREATMENT (12)

Soil constant= 2.600 Altitude= 2500.000 feet Wind speed= 27.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	10.00	1000.0	16.00	2084	.56	1292	126.2	35.4	4.83	32.4	1292	0	.0	38	1.10	2.50	0
2	-.01	1000.0	12.00	3126	.74	1314	48.5	5.2	4.91	14.5	1314	0	.0	45	1.25	2.50	4
3	89.99	500.0	10.00	2084	1.28	396	104.5	12.1	15.40	75.1	396	0	.0	50	1.70	2.50	0
4	20.00	500.0	7.00	1042	.80	1836	143.3	22.8	8.15	48.3	1836	0	.0	52	1.30	2.50	0
5	-30.00	500.0	6.00	3126	1.04	4	3091.0	9999.9	.00	30.0	4	0	.0	4	1.50	2.50	0

TREATMENT (13)

Soil constant= 3.300 Altitude= 2500.000 feet Wind speed= .000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	.01	1000.0	16.00	2084	.56	1017	21.4	1.0	4.54	23.9	1017	0	.0	57	1.10	2.50	4
2	-10.00	1000.0	12.00	3126	.74	1256	102.8	23.5	5.60	48.1	1256	0	.0	42	1.25	2.50	1
3	80.00	500.0	10.00	2084	1.28	265	100.9	11.3	15.18	89.3	265	0	.0	50	1.70	2.50	0
4	10.00	500.0	7.00	1042	.80	1403	135.9	20.5	5.08	31.7	1403	0	.0	38	1.30	2.50	0
5	-40.00	500.0	6.00	3126	1.04	3	3098.4	9999.9	.00	40.0	3	0	.0	3	1.50	2.50	0

TREATMENT (14)

Soil constant= 3.300 Altitude= 2500.000 feet Wind speed= 27.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	.01	1000.0	16.00	2084	.56	1165	42.1	3.9	5.03	16.9	1165	0	.0	48	1.10	2.50	4
2	-10.00	1000.0	12.00	3126	.74	1408	122.3	33.2	5.64	38.9	1408	0	.0	42	1.25	2.50	1
3	80.00	500.0	10.00	2084	1.28	657	104.7	12.2	15.20	74.4	657	0	.0	50	1.70	2.50	0
4	10.00	500.0	7.00	1042	.80	1535	158.6	27.9	5.13	27.0	1535	0	.0	38	1.30	2.50	0
5	-40.00	500.0	6.00	3126	1.04	3	3098.7	9999.9	.00	40.0	3	0	.0	3	1.50	2.50	0

TREATMENT (15)

Soil constant= 3.300 Altitude= 2500.000 feet Wind speed= .000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTN	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	10.00	1000.0	16.00	2084	.56	1162	104.6	24.3	4.80	40.1	1162	0	.0	38	1.10	2.50	0
2	-.01	1000.0	12.00	3126	.74	1173	24.5	1.3	4.63	22.7	1173	0	.0	55	1.25	2.50	4
3	89.99	500.0	10.00	2084	1.28	0	100.9	11.3	15.40	90.0	0	0	.0	50	1.70	2.50	0
4	20.00	500.0	7.00	1042	.80	1625	126.9	17.9	8.06	56.8	1625	0	.0	52	1.30	2.50	0
5	-30.00	500.0	6.00	3126	1.04	4	3090.5	9999.9	.00	30.0	4	0	.0	4	1.50	2.50	0

TREATMENT (16)

Soil constant= 3.300 Altitude= 2500.000 feet Wind speed= 27.000 feet/second

FRAG	E	WT	A/M	IV	CD	DISTH	VF	KE	TOF	EF	RANGE	XRN	XA	XD	AR	HO	RB
1	10.00	1000.0	16.00	2084	.56	1292	126.2	35.4	4.83	32.4	1292	0	.0	38	1.10	2.50	0
2	-.01	1000.0	12.00	3126	.74	1324	45.4	4.6	5.10	16.4	1324	0	.0	48	1.25	2.50	4
3	89.99	500.0	10.00	2084	1.28	396	104.5	12.1	15.40	75.1	396	0	.0	50	1.70	2.50	0
4	20.00	500.0	7.00	1042	.80	1836	143.3	22.8	8.15	48.3	1836	0	.0	52	1.30	2.50	0
5	-30.00	500.0	6.00	3126	1.04	4	3091.0	9999.9	.00	30.0	4	0	.0	4	1.50	2.50	0

TABLE 1 Increment = 100 feet Number of Units= 46

Distance (feet)		Total	Total Density	Total	Hazard	Hazard Density	Hazard	----- Total Number of Final Ground Impacts ----- 10 Degree Azimuth Sector		
From	To	No.	Frags/sqft	P-hit	No.	Frags/sqft	P-hit	Min	Avg	Max
0	100	188.60	1.340030	.999441	187.74	1.339041	.999440	59.80	60.95	64.40
100	200	43.70	.283663	.801686	43.70	.283663	.801686	.00	.00	.00
200	300	44.85	.163324	.605602	43.70	.163060	.605533	.00	1.15	4.60
300	400	44.85	.109041	.462737	43.70	.108349	.462544	.00	1.15	4.60
400	500	43.70	.075183	.347950	43.70	.075183	.347950	.00	.00	.00
500	600	43.70	.057279	.278961	43.70	.057279	.278961	.00	.00	.00
600	700	44.85	.052220	.257525	43.70	.052117	.257370	.00	1.15	4.60
700	800	43.70	.040679	.205050	42.84	.040254	.202762	.00	.00	.00
800	900	43.70	.028310	.149021	33.35	.021858	.114816	.00	.00	.00
900	1000	43.70	.020578	.110382	20.01	.009943	.053264	.00	2.59	41.40
1000	1100	35.36	.013311	.071757	5.75	.003644	.019179	.00	7.76	41.40
1100	1200	43.70	.009975	.053552	.29	.000117	.000636	.00	32.20	87.40
1200	1300	30.47	.004494	.023002	.00	.000000	.000000	.00	18.98	46.00
1300	1400	26.45	.002951	.015328	.00	.000000	.000000	.00	17.25	46.00
1400	1500	14.95	.000927	.004431	.00	.000000	.000000	.00	14.95	46.00
1500	1600	12.08	.000801	.004033	.00	.000000	.000000	.00	12.07	82.80
1600	1700	9.20	.000369	.001329	.00	.000000	.000000	.00	9.20	36.80
1700	1800	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00
1800	1900	9.20	.000364	.001536	.00	.000000	.000000	.00	9.20	36.80
1900	2000	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00
2000	2100	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00
2100	2200	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00
2200	2300	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00
2300	2400	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00

Number of trajectories with distance greater than 2400 feet= 0

TABLE 2 Increment= 100 feet Number of Units= 46

Distance (feet)	Hazard Density (Frags/sqft) Max	90%	50%	Min	Hazard Probability of Hit Max	90%	50%	Min
50	1.357916	1.357916	1.334788	1.307392	.999510	.999510	.999442	.999337
150	.300836	.300836	.266695	.265379	.821109	.821109	.782552	.782160
250	.176118	.176118	.150552	.149702	.634923	.634923	.577523	.575474
350	.120446	.120446	.098275	.096766	.498069	.498069	.430347	.425433
450	.087444	.087444	.064626	.062182	.393847	.393847	.309237	.299475
550	.059822	.059590	.056720	.054291	.289930	.288982	.277012	.266884
650	.056120	.055912	.051345	.049085	.274698	.273839	.254437	.245060
750	.055907	.055856	.030474	.019872	.273727	.273514	.160436	.107860
850	.036124	.036111	.027168	.000000	.187052	.186990	.144520	.000000
950	.023708	.022748	.006292	.000000	.127069	.122276	.035363	.000000
1050	.029482	.028820	.000000	.000000	.155394	.152126	.000000	.000000
1150	.001868	.000000	.000000	.000000	.010662	.000000	.000000	.000000
1250	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1350	.000000	.000000	.000000	.000000	000000	.000000	.000000	.000000
1450	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1550	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1650	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1750	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1850	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1950	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2050	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2150	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2250	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2350	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000

TABLE 3 Increment= 100 feet

HAZARD DISTANCE (FEET)	NUMBER OF UNITS TO JUST EXCEED: DENSITY CRITERION MIN	90%	50%	MAX	P-HIT CRITERION MIN	90%	50%	MAX
50	.07	.07	.07	.07	.07	.07	.07	.07
150	.26	.26	.30	.30	.28	.28	.31	.31
250	.45	.45	.52	.52	.47	.47	.55	.55
350	.65	.65	.79	.81	.68	.68	.83	.94
450	.89	.89	1.20	1.24	.92	.92	1.26	1.33
550	1.29	1.29	1.36	1.42	1.26	1.27	1.44	1.50
650	1.38	1.38	1.50	1.57	1.45	1.45	1.58	1.65
750	1.38	1.38	2.51	2.67	1.46	1.46	2.65	4.66
850	2.17	2.17	2.87	999999.00	2.24	2.24	2.97	999999.00
950	3.24	3.28	12.15	999999.00	2.41	3.53	12.65	999999.00
1050	2.61	2.67	999999.00	999999.00	2.75	2.81	999999.00	999999.00
1150	41.45	999999.00	999999.00	999999.00	42.14	999999.00	999999.00	999999.00
1250	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1350	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1450	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1550	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1650	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1750	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1850	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1950	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
2050	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
2150	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
2250	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
2350	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00

The 999999.00 entries signify that the number of units required is infinite, that is, the Hazard Density and P-hit are both zero.

Hazard Density Criterion= .001667 frag/sqft Hazard P-hit Criterion= .010

TABLE 1 Increment = 200 feet Number of Units= 46

Distance (feet) From	To	Total No.	Total Density Frags/sqft	Total P-hit	Hazard No.	Hazard Density Frags/sqft	Hazard P-hit	----- Total Number of Final Ground Impacts ----- 10 Degree Azimuth Sector Min	Avg	Max
0	200	232.30	.547755	.851124	231.44	.547508	.851124	59.90	60.95	64.40
200	400	89.70	.131659	.522364	87.40	.131407	.522123	.00	2.30	9.20
400	600	87.40	.065336	.310066	87.40	.065336	.310066	.00	.00	.00
600	800	88.55	.046038	.229413	86.54	.045761	.228116	.00	1.15	4.60
800	1000	87.40	.024229	.128628	53.36	.015570	.082330	.00	2.59	41.40
1000	1200	77.06	.011558	.062241	6.04	.001800	.009486	.00	39.96	128.80
1200	1400	56.93	.003693	.019017	.00	.000000	.000000	.00	36.22	92.00
1400	1600	27.03	.000862	.004225	.00	.000000	.000000	.00	27.02	126.80
1600	1800	9.20	.000179	.000645	.00	.000000	.000000	.00	9.20	36.80
1800	2000	9.20	.000177	.000748	.00	.000000	.000000	.00	9.20	36.80
2000	2200	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00
2200	2400	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00

Number of trajectories with distance greater than 2400 feet= 0

TABLE 2 Increment= 200 feet Number of Units= 46

Distance (feet)	---------- Hazard Density (Frags/sqft) ---------- Max	90%	50%	Min	---------- Hazard Probability of Hit ---------- Max	90%	50%	Min
100	.565106	.565106	.533719	.526632	.865709	.865709	.836775	.836454
300	.143643	.143643	.120057	.118823	.555091	.555091	.491670	.487950
500	.072252	.072124	.060278	.057842	.336692	.336171	.291513	.281559
700	.056005	.055852	.040164	.033435	.274178	.273665	.204079	.171560
900	.029571	.029058	.016160	.000000	.155394	.152815	.086909	.000000
1100	.015947	.013755	.000000	.000000	.079738	.072606	.000000	.000000
1300	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1500	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1700	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1900	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2100	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2300	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000

TABLE 3 Increment= 200 feet

HAZARD DISTANCE (FEET)	NUMBER OF UNITS TO JUST EXCEED: DENSITY CRITERION MIN	90%	50%	MAX	P-HIT CRITERION MIN	90%	50%	MAX
100	.15	.15	.15	.16	.16	.16	.17	.17
300	.54	.54	.65	.66	.57	.57	.68	.69
500	1.07	1.07	1.28	1.34	1.13	1.13	1.35	1.41
700	1.38	1.38	1.92	2.30	1.45	1.46	2.02	2.42
900	2.60	2.65	4.75	999999.00	2.74	2.79	5.00	999999.00
1100	5.11	5.58	999999.00	999999.00	5.33	5.89	999999.00	999999.00
1300	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1500	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1700	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1900	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
2100	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
2300	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00

The 999999.00 entries signify that the number of units required is infinite, that is, the Hazard Density and P-hit are both zero.

Hazard Density Criterion= .001667 frag/sqft Hazard P hit Criterion= .010

TABLE 1 Increment = 300 feet Number of Units= 46

Distance (feet) From	To	Total No.	Total Density Frags/sqft	Total P-hit	Hazard No.	Hazard Density Frags/sqft	Hazard P-hit	Total Number of Final Ground Impacts, 10 Degree Azimuth Sector: Min	Avg	Max
0	300	277.15	.334182	.714723	275.14	.333926	.714685	59.80	62.10	69.00
300	600	132.25	.076667	.349603	131.10	.076617	.349553	.00	1.15	4.60
600	900	132.25	.039340	.199043	119.89	.036731	.185314	.00	1.15	4.60
900	1200	122.76	.014285	.076759	26.05	.004256	.022689	.00	42.55	170.20
1200	1500	71.88	.002702	.013795	.00	.000000	.000000	.00	51.17	138.00
1500	1800	21.28	.000374	.001706	.00	.000000	.000000	.00	21.27	119.60
1800	2100	9.20	.000115	.000486	.00	.000000	.000000	.00	9.20	36.80
2100	2400	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00

Number of trajectories with distance greater than 2400 feet= 0

TABLE 2 Increment= 300 feet Number of Units= 46

Distance (feet)	Hazard Density (Frags/sqft) Max	90%	50%	Min	Hazard Probability of Hit Max	90%	50%	Min
150	.349001	.349001	.320848	.317226	.737495	.737495	.692746	.691465
450	.084747	.084652	.070129	.067933	.378531	.378144	.327507	.318853
750	.048495	.048413	.035262	.020804	.241764	.240921	.181579	.106749
1050	.017659	.016467	.001895	.000000	.094013	.087574	.010665	.000000
1350	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1650	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1950	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2250	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000

TABLE 3 Increment= 300 feet

HAZARD DISTANCE (FEET)	NUMBER OF UNITS TO JUST EXCEED: DENSITY CRITERION MIN	90%	50%	MAX	P-HIT CRITERION MIN	90%	50%	MAX
150	.23	.23	.25	.25	.25	.25	.27	.27
450	.91	.92	1.10	1.14	.96	.96	1.16	1.20
750	1.59	1.59	2.18	3.70	1.68	1.68	2.30	3.87
1050	4.35	4.67	40.41	999999.00	4.58	4.91	42.60	999999.00
1350	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1650	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1950	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
2250	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00

The 999999.00 entries signify that the number of units required is infinite,
that is, the Hazard Density and P-hit are both zero.
Hazard Density Criterion= .001667 frag/sqft Hazard P-hit Criterion= .010

TABLE 1   Increment = 400 feet   Number of Units= 46

Distance (feet) From	To	Total No.	Total Density Frags/sqft	Total P-hit	Hazard No.	Hazard Density Frags/sqft	Hazard P-hit	Total Number of Final Ground Impacts, 10 Degree Azimuth Sector: Min	Avg	Max
0	400	322.00	.235683	.604479	318.84	.235455	.604373	59.80	63.25	73.60
400	800	175.95	.054079	.262994	173.94	.053917	.262237	.00	1.15	4.60
800	1200	166.46	.017265	.092115	59.40	.007597	.042266	.00	42.55	170.20
1200	1600	85.95	.002176	.011093	.00	.000000	.000000	.00	63.25	220.80
1600	2000	18.40	.000178	.000699	.00	.000000	.000000	.00	18.40	73.60
2000	2400	.00	.000000	.000000	.00	.000000	.000000	.00	.00	.00

Number of trajectories with distance greater than 2400 feet= 0

TABLE 2   Increment= 400 feet   Number of Units= 46

Distance (Feet)	Hazard Density (Frags/sqft) Max	90%	50%	Min	Hazard Probability of Hit Max	90%	50%	Min
200	.249008	.249008	.223472	.220775	.632746	.632746	.577946	.575076
600	.062775	.062649	.048545	.043305	.300225	.299709	.240510	.217389
1000	.021583	.020641	.007272	.000000	.113784	.108700	.039109	.000000
1400	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1800	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2200	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000

TABLE 3   Increment= 400 feet

HAZARD DISTANCE (FEET)	NUMBER OF UNITS TO JUST EXCEED: DENSITY CRITERION MIN	90%	50%	MAX	P-HIT CRITERION MIN	90%	50%	MAX
200	.32	.32	.35	.36	.34	.34	.38	.39
600	1.23	1.23	[illegible]	1.77	1.30	1.30	1.67	1.86
1000	3.56	3.72	10.55	999999.00	3.75	3.92	11.10	999999.00
1400	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
1800	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00
2200	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00	999999.00

The 999999.00 entries signify that the number of units required is infinite,
that is, the Hazard Density and P-hit are both zero.
Hazard Density Criterion= .001657 frag/sqft   Hazard P-hit Criterion= .010

TABLE H-3. TEST CASE FRAGMENTATION DATA

```
.01 .02 .03 .04 .05 .06 .07 .08 .09 .10 .11 .12 .13
90 1000 16 2000 1.1
100 1000 12 3000 1.25
10 500 10 2000 1.7
80 500 7 1000 1.3
130 500 6 3000 1.5
.10 .25 .60 .80 a
.5 a
0 .9999 a
1.2 a
.5 a
.5 a
0 .90 a
```

APPENDIX I

WEAPON FRAGMENTATION DATA

INTRODUCTION

Tables I-1 and I-2 contain the fragmentation data for 155mm projectiles (M107) and Mk82 Low Drag Bombs. They are intended for use with the FRAGHAZ program as described in Listing B-1 of Appendix B.

The data for each weapon are divided into three parts.

Part 1 - The first 13 values in the tables are the fragment multipliers as described in Appendix D. Each multiplier represents the effective number of fragments for one degree of azimuth and one unit or interaction area. The first multiplier is for polar zone 0 to 10 deg, the second for polar zone 10 to 20 deg and so on to the 13th multiplier which is for polar zone 120 to 130 deg.

Part 2 - The next 215 lines for 155mm projectiles, and the next 260 lines for Mk82 bombs contain the five characteristics for each fragment associated with the respective weapon. The five values for each fragment are described as follows:

Value 1 - The upper angle for the 10 deg polar zone containing the fragment. For example an entry of 40 would specify polar zone 30 to 40 deg. Remember that the elevation zones are derived from the polar zones as follows

$$EL = 90 - PA$$

where

EL - The lower limit of the 10 deg elevation zone. EL may be as negative as -40.

PA - Upper limit of the 10 deg polar zone.

Value 2 - Weight of the fragment in grains.

Value 3 - The average presented area to mass ratio (in^2/lb) which is used in drag calculations.

Value 4 - Average initial fragment velocity (ft/s)

Value 5 - The ratio of maximum presented area to average presented area used to calculate the drag coefficient at a Mach Number of approximately 0.1.

Part 3 The last seven lines in the tables are the factor levels for the seven random variables used in the FULL FACTORIAL option only. Except for Height of Origin, the pair of levels for all other random variables span 80 percent of the range of uncertainty. For example, if the total range of uncertainty were 10 to 20 then the factor levels would be 11 and 19. This accounts for five pairs of levels marked 0.1 and 0.9. For velocity, which is distributed normally, the entries -1.28 and 1.28 are standard deviations which again span 80 percent of the uncertainty. The variables associated with each line are as follows.

Line	Random Variable
1	Soil Constant
2	Height of Origin
3	Initial Elevation Angle
4	Initial Velocity
5	Drag Coefficient
6	Site Altitude
7	Wind Speed

The "a" at the end of each line will produce a READ error in line 262 as shown in the FRAGHAZ program listing in Appendix B. After encountering the error the program will skip to the next factor level line to read the factor levels for the next random variable.

There is nothing absolute about the factor levels shown and users may want to change them to suit their particular needs.

TABLE I-1 FRAGMENTATION DATA FOR 155MM PROJECTILES (M107)

```
.000925  .0016  .003  .00416  .00517  .006  .00666  .0071  .02126  .02346
.11715 .00666 .006
10  539  9.59  2750  1.37
10  883  8.88  2750  1.35
10  904  7.53  2750  1.27
.0  1015  6.41  2750  1.4
10  1276  7.78  2750  1.41
10  1393  8.39  2750  1.49
10  1834  7.74  2750  1.46
10  3279  6.21  2750  1.46
10  560  9.47  2750  1.2
10  561  10.73  2750  1.51
10  595  9.55  2750  1.32
10  606  10.32  2750  1.4
10  737  9  2750  1.29
10  747  8.40  2750  1.32
10  1014  9.45  2750  1.5
10  1080  9.13  2750  1.5
10  1411  8.33  2750  1.4
10  2628  6.68  2750  1.46
20  501  11.38  2260  1.29
20  514  12.44  2260  1.58
20  546  9.7  2260  1.29
20  567  10.37  2260  1.2
20  703  9.40  2260  1.23
20  1148  7.98  2240  1.4
20  636  8.58  2260  1.27
20  669  9.54  2260  1.13
20  769  9.16  2260  1.22
20  862  8.83  2260  1.16
30  541  13.06  2540  1.58
30  1921  6.74  2540  1.37
30  1993  12.46  2540  1.75
40  683  9.92  2580  1.32
40  719  10.1  2580  1.28
40  1016  8.61  2580  1.4
40  1212  8.95  2580  1.5
40  597  10.06  2580  1.28
40  609  13.23  2580  1.42
40  720  10.61  2580  1.44
60  610  10.38  6300  1.3
70  567  10.2  5838  1.22
70  571  10.33  5838  1.41
70  710  10.56  5838  1.42
70  966  10.86  5838  1.57
70  3636  7.87  5838  1.65
70  562  9.21  5838  1.2
80  548  11.6  5395  1.17
80  890  10.66  5395  1.64
80  1778  10.29  5395  1.62
80  3171  8.69  5395  1.86
80  604  37.55  5395  1.61
80  620  10.77  5375  1.49
80  727  19.35  5395  1.47
80  777  10.27  5395  1.4
80  1239  9.49  5395  1.51
80  595  10.9  5395  1.35
80  617  9.31  5395  1.27
80  1301  10.[illegible]  5395  1.72
80  2206  7.9  5395  1.69
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80	2503	9.03	5395	1.65
80	2457	8.24	5080	1.61
90	543	11.32	5040	1.64
90	734	11.03	5040	1.65
90	880	9.09	5040	1.55
90	912	10.19	5040	1 56
90	1391	9.71	5040	1.59
90	1995	9.89	5040	1.66
90	542	17.45	5040	1.49
90	923	7.47	5040	1.21
90	547	11.35	5040	1.31
90	617	12.52	5040	1.62
90	767	11.07	5040	1.44
90	1040	9.69	5040	1.51
90	6922	5.73	5040	1.59
90	604	10.51	5040	1.45
90	2430	7 48	5040	1.49
90	6342	6.82	5040	1.66
100	805	9.35	4600	1.48
100	921	7.63	4600	1.31
100	1800	6.72	4600	1.39
100	2007	6.48	4600	1.36
100	2764	10.13	4600	1.71
100	4546	7.14	4600	1.53
100	8168	4.34	4600	1.44
100	592	12.49	4600	1.45
100	1052	32.2	4600	1.73
100	1441	8.95	4600	1.55
100	9224	5.48	4600	1.61
100	547	10.95	4600	1.47
100	575	17.82	4600	1.41
100	629	11.89	4600	1.51
100	706	9.45	4600	1.37
100	741	13.69	4600	1.64
100	749	10.14	4600	1.48
100	924	11.19	4600	1.48
100	995	10.62	4600	1.57
100	1019	10.73	4600	1.58
100	1138	11.74	4600	1.65
100	1204	9.72	4600	1.56
100	1416	13.18	4600	1.71
100	1618	8.45	4600	1.5
100	1878	7.38	4600	1.46
100	2207	8 88	4600	1.61
100	2287	14.12	4600	1.82
100	2348	7.55	4600	1.55
100	2562	7.85	4600	1.59
100	2670	9.42	4600	1.6
100	2687	8.60	4600	1.6
100	3438	8.51	4600	1.67
100	3568	6.66	4600	1.46
100	4658	6.87	4600	1.58
100	6505	5.05	4600	1.46
100	7430	5.21	4600	1.51
100	10679	5.59	4600	1.53
100	11020	4.09	4600	1.47
110	507	12.29	4600	1.47
110	606	13.42	4600	1.52
110	732	11.25	4600	1.67
110	1388	10.84	4600	1.65

110	1556	9.62	4600	1.58
110	1989	9.60	4600	1.66
110	2545	28.88	4600	1.64
110	23768	4.24	4600	1.62
10	465	10.77	2750	1.47
10	480	10.82	2750	1.6
10	321	12.83	2750	1.32
10	330	11.19	2750	1.27
10	354	10.53	2750	1.14
10	357	12.28	2750	1.5
10	372	11.8	2750	1.53
10	437	11.21	2750	1.3
10	445	11.64	2750	1.42
20	324	14.42	2260	1.54
20	333	11.68	2260	1.22
20	395	13.17	2260	1.65
20	419	12.17	2260	1.48
20	363	11.62	2260	1.44
20	443	9.46	2260	1.35
20	445	9.92	2260	1.46
20	454	10.7	2260	1.17
20	483	10.97	2260	1.41
20	489	12	2260	1.11
30	317	17.14	2540	1.74
30	405	15.78	2540	1.71
30	464	10.72	2540	1.15
30	315	14.7	2540	1.52
30	348	13.15	2540	1.24
30	394	14.34	2540	1.65
30	418	10.73	2540	1.17
40	311	11.75	2580	1.34
40	353	19.75	2580	1.4
40	367	11.93	2580	1.13
40	478	13.49	2580	1.5
40	377	14.17	2580	1.59
60	429	10.66	6500	1.25
60	303	12.81	6500	1.46
70	335	13.3	5838	1.35
70	350	11.67	5838	1.2
70	445	9.77	5838	1.24
70	351	12.72	5838	1.53
70	475	13.56	5838	1.54
70	367	16.45	5838	1.75
70	422	14.76	5838	1.79
70	447	13.69	5838	1.51
70	483	12.82	5838	1.69
70	487	14.69	5838	1.67
70	487	13.04	5838	1.61
70	390	14.69	5838	1.51
70	392	13.67	5838	1.4
80	316	12.27	5395	1.53
80	345	13.98	5395	1.32
80	348	13.54	5395	1.6
80	382	15.49	5395	1.62
80	469	10.77	5395	1.69
80	362	14.24	5395	1.57
80	303	12.37	5395	1.42
80	312	12.55	5395	1.32
80	318	13.62	5395	1.61
80	320	13.35	5395	1.42

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80  326  16.89  5395  1.55
80  345  15.51  5395  1.57
80  352  14.6  5395  1.55
80  362  11.8  5395  1.21
80  373  10.74  5395  1.28
80  374  12.14  5395  1.55
80  393  13.59  5395  1.52
80  417  10.7  5395  1.26
80  439  14.73  5395  1.78
80  488  13.09  5395  1.63
80  491  11.26  5395  1.5
90  302  15.35  5040  1.64
90  306  13.34  5040  1.66
90  354  12.13  5040  1.34
90  381  11.55  5040  1.33
90  429  9.89  5040  1.28
90  477  13.48  5040  1.73
90  410  12.94  5040  1.41
90  304  13.47  5040  1.47
90  313  11.79  5040  1.46
90  454  10.69  5040  1.53
90  451  14.91  5040  1.59
 100  303  15.18  4600  1.57
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 100  345  16.06  4600  1.54
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 100  361  13.38  4600  1.49
 100  456  13.59  4600  1.55
 100  462  12.45  4600  1.37
 100  309  17.81  4600  1.65
 100  329  15.53  4600  1.63
 100  367  17.38  4600  1.64
 100  403  14.74  4600  1.54
 100  435  15.38  4600  1.66
 100  441  16.06  4600  1.62
 100  492  17.45  4600  1.7
 100  495  16.13  4600  1.73
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.10 .90 a
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.10 .90 a
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TABLE I 2. FRAGMENTATION DATA FOR MK82 LOW DRAG BOMBS

.1 .1 .1 .1 .1 .1 .11767 .11767 .11767 .11767 .11767 .1 .1

10	1118.8	10.89	9070	1.62
10	661.5	11.81	9070	1.6
20	621	12.15	10869	1.61
20	681.9	11.54	10869	1.42
20	1214.7	12.1	10869	1.68
20	1496.2	11.13	10869	1.7
20	526.9	11.45	10869	1.59
20	683.2	12.6	10869	1.42
20	832.7	10.3	10869	1.43
20	921.5	9.84	10869	1.57
30	509.5	11.64	10869	1.57
30	716.5	10.11	10869	1.3
30	687.2	10.1	10869	1.56
30	747.5	10.69	10869	1.46
30	568.1	12.24	10869	1.59
40	729.1	10.38	9709	1.31
40	938.1	10.81	9709	1.61
40	1796.2	23.3	9709	1.68
50	516.4	12.31	6600	1.49
50	563	13.83	6600	1.46
50	1322.1	9.53	6600	1.47
50	964.1	9.37	6600	1.75
50	872.6	10.17	6600	1.56
50	5493.2	7.42	6600	1.65
60	1205.8	10.86	8869	1.59
60	3927.4	8.29	8869	1.68
60	1748.7	12.33	8869	1.68
60	581.7	15.44	8869	1.39
60	1437.5	10.57	8869	1.63
60	1818	9.36	8869	1.63
60	500.4	10.16	8869	1.46
70	1105.3	11.65	10870	1.65
70	572.4	12.23	10870	1.47
70	575.7	12.12	10870	1.48
70	514.3	11.22	10870	1.48
70	886.4	9.75	10870	1.59
70	629.1	11.39	10870	1.57
70	1363.6	11.86	10870	1.63
70	845.4	10.57	10870	1.47
80	873.8	10.31	10870	1.43
80	555.7	11.44	10870	1.56
80	851.2	11.5	10870	1.54
80	1800.2	9.8	10870	1.61
80	517.5	16.16	10870	1.25
80	588.8	11.13	10870	1.6
80	728.3	10.57	10870	1.32
80	1054.9	12.61	10870	1.66
80	1580.9	11.07	10870	1.66
80	2562.7	8.90	10870	1.63
80	578.8	10.8	10870	1.58
80	541.5	12.75	10870	1.32
80	1786.2	11.36	10870	1.65
80	2085.4	11.61	10870	1.68
80	1230	11.38	10870	1.63
80	508.8	12.37	10870	1.66
90	1165.5	13.69	9324	1.682
90	505.2	12.82	9324	1.58
90	524	13.35	9324	1.56
90	534.6	12.62	9324	1.54

90	672.1	11.97	9324	1.63
90	1064.6	9.47	9324	1.52
90	517.4	11.58	9324	1.56
90	593.8	11.19	9324	1.67
90	1297.4	9.31	9324	1.65
90	516.8	12.27	9324	1 4
90	578.5	10.07	9324	1.52
90	670.6	11.49	9324	1.52
90	1046.7	12.37	9324	1.65
90	750.9	10.38	9324	1.48
90	863.3	11.38	9324	1.59
90	879.4	10.14	9324	1.51
90	944.2	11.64	9324	1.62
90	1077.6	12.21	9324	1.66
90	657.8	10.27	9324	1.6
90	877	10.14	9324	1.65
90	1297.3	12.57	9324	1.67
100	515.8	12.95	7576	1.48
100	789.9	11.29	7576	1.66
100	513.2	12.19	7576	1.54
100	624.7	12.3	7576	1.64
100	880.8	12.08	7576	1.62
100	528.8	13.2	7576	1.63
100	767.4	10.6	7576	1.6
100	902.9	11.04	7576	1.45
100	904.5	9.72	7576	1.31
100	647	11.94	7576	1.52
100	838.3	9.86	7576	1.33
100	1181.3	9.54	7576	1.55
100	1204.1	8.72	7576	1.47
100	1632.9	11.45	7576	1.67
100	3503.7	4.85	7576	1.27
110	770.7	12.82	7380	1.74
110	1018.8	13.26	7380	1.66
110	634.1	10.27	7380	1.39
110	588.3	9.91	7380	1.29
110	546.2	11.93	7380	1.57
110	588.5	12.8	7380	1.63
110	1149.4	13.22	7380	1.68
110	705	11.18	7380	1.59
110	1146.3	10.63	7380	1.59
110	1852.1	10.28	7380	1.67
110	2363.5	10.37	7380	1.64
110	613.5	12.69	7380	1.58
110	656.5	11.07	7380	1.46
110	896	10.95	7380	1.72
110	2265.1	8.90	7380	1.61
110	520.1	9.97	7380	1.26
110	807.7	10.05	7380	1.64
110	942.8	10.78	7380	1.52
110	1023.1	11.63	7380	1.62
110	1497.7	8.97	7380	1.54
110	1682.1	8.82	7380	1.57
120	814	11.64	7678	1.65
120	635.7	12.56	7678	1.82
120	911.7	11.05	7678	1.7
120	642.2	11.51	7678	1.62
120	799.7	13.23	7678	1.71
120	689.2	10.9	7678	1.57
120	1197.5	12.22	7678	1.69

120	688.9	11.7	7678	1.73
120	703.6	10.02	7678	1.51
120	597	11.36	7678	1.65
120	891.9	9.95	7678	1.66
120	1178.6	13.48	7678	1.7
120	540.2	12.6	7678	1.53
120	773	11.47	7678	1.61
120	649.6	12.24	7678	1.54
120	1021.6	12.95	7678	1.66
120	2644.6	9.45	7678	1.67
120	625.6	12.07	7678	1.55
120	796.8	10.63	7678	1.55
130	1303.2	11.66	7105	1.64
130	655.2	11.96	7105	1.72
130	684.2	10.79	7105	1.66
130	1387	11.41	7105	1.67
130	3718.8	9.84	7105	1.74
130	712.3	14.02	7105	1.77
130	613.4	13.66	7105	1.78
130	648.6	12.37	7105	1.62
130	726.5	10.71	7105	1.42
130	784.4	11.82	7105	1.73
130	930.9	10.59	7105	1.44
130	2779.7	10.98	7105	1.7
130	511.4	14.06	7105	1.68
130	778.6	12.42	7105	1.67
130	1105.2	13.11	7105	1.7
130	1665.3	8.49	7105	1.53
130	597.2	13.37	7105	1.73
130	1168.7	15.03	7105	1.73
20	346.6	11.9	10869	1.52
20	374.2	11.15	10869	1.25
20	435.2	11.39	10869	1.36
20	345	13.76	10869	1.56
20	357.4	15.63	10869	1.42
20	390.4	13.13	10869	1.58
20	335.3	12.88	10869	1.68
30	321.7	14.95	10869	1.62
30	446.9	14	10869	1.61
30	327.6	14.23	10869	1.37
30	406.8	12.72	10869	1.28
40	430.1	11.8	9709	1.56
40	394.6	12.74	9709	1.43
40	407	15.32	9709	1.53
40	494.4	12.95	9709	1.56
50	348.3	15.78	6600	1.48
50	304	14.6	6600	1.45
50	358.1	15.38	6600	1.52
50	350.8	15.86	6600	1.46
50	372.6	14.22	6600	1.47
50	302.2	15.31	6600	1.49
50	321.9	14.44	6600	1.6
50	445.6	12.52	6600	1.5
50	424.9	16.66	6600	1.33
60	308.5	17.2	8869	1.41
60	316.5	15.75	8869	1.46
60	385.6	14.81	8869	1.54
60	357.1	12.29	8869	1.33
60	407.7	12.98	8869	1.3
60	446	13.69	8869	1.59

70	450.6	11.25	10870	1.58
70	469.3	15.32	10870	1.54
70	394	12.56	10870	1.49
70	462.6	12.3	10870	1.42
70	378.8	16.41	10870	1.35
70	388.3	12.31	10870	1.45
70	408.7	10.19	10870	1.21
70	387.1	14.14	10870	1.64
80	453.5	15.87	10870	1.62
80	314.3	13.16	10870	1.44
80	428.5	12.4	10870	1.55
80	455.8	14.59	10870	1.61
80	303.3	14.61	10870	1.5
80	347.2	13.23	10870	1.63
80	429.7	12.07	10870	1.58
80	306.9	15.21	10870	1.57
80	322.9	13.61	10870	1.4
80	496	13.45	10870	1.58
80	395.5	15.79	10870	1.42
80	354.2	13.42	10870	1.5
90	314	14.96	10870	1.54
80	440.9	13.4	10870	1.44
80	313.3	13.2	10870	1.47
80	334.3	15.89	10870	1.45
80	431.1	12.7	10870	1.57
80	493.4	11.48	10870	1.37
90	310.6	14.38	9324	1.59
90	357.4	15.14	9324	1.6
90	381.9	15.16	9324	1.57
90	480.7	13.28	9324	1.46
90	310.7	14.6	9324	1.52
90	344.1	13.67	9324	1.3
90	491.8	10.93	9324	1.43
90	310.1	13.23	9324	1.34
90	308.5	14.5	9324	1.5
90	382.5	18.79	9324	1.69
90	483.4	11.27	9324	1.44
90	349.2	12.25	9324	1.4
90	361.8	11.43	9324	1.49
90	491.1	13.87	9324	1.54
90	316.6	12.2	9324	1.71
90	330.4	14.79	9324	1.76
90	308.2	15.31	9324	1.52
90	326.4	12.61	9324	1.48
90	350.7	11.38	9324	1.36
90	462.1	13.38	9324	1.57
90	492.2	13.13	9324	1.52
90	431.8	12.09	9324	1.47
90	420.7	13.51	9324	1.51
100	455.8	12.78	7576	1.61
100	337.3	15.77	7576	1.52
100	457	13.54	7376	1.48
100	469.7	12.7	7576	1.42
100	349.5	13.84	7576	1.21
100	336.3	15.03	7576	1.43
110	403.5	14.31	7380	1.54
110	411	13.06	7380	1.6
110	337.3	15.19	7380	1.58
110	391.5	14.97	7380	1.52
110	431.8	12.55	7380	1.7

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110  491.7  11.97  7380  1.48
110  355.3  14.62  7380  1.57
110  363.2  14.45  7380  1.51
110  457.8  12.45  7380  1.44
110  349.5  11.92  7380  1.51
110  371  14.02  7380  1.55
110  373.1  12.91  7380  1.45
110  315.5  13  7380  1.47
110  485.6  11.81  7380  1.52
120  416.9  12.96  7678  1.47
120  371.5  12.91  7678  1.41
120  384.9  12.31  7678  1.46
120  453.4  13.46  7678  1.36
120  357.3  12.28  7678  1.5
130  317  16.8  7105  1.42
130  358.9  14.16  7105  1.47
130  399.2  14.69  7105  1.67
130  417.1  12.37  7105  1.59
130  486  12.26  7105  1.63
130  367.2  16.73  7105  1.61
130  487.6  12.86  7105  1.67
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